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Journal
of
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Devoted to Science and the Mechanic Arts

Vol. 225 FEBRUARY, 1938 No. 2

PROGRESS OF THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.*

BY

DR. ELLICE McDONALD,

Director.

Our Foundation in the last year has grown in wisdom and stature. We have increased in numbers, now 56, and have developed new avenues of research. We take this opportunity of laying before you *in extenso* what we have done in the last year and what we are doing now and what we will be doing in the near future. We are the more glad to do this to show by example that a laboratory which has the right to take out patents on medical discoveries can expose all its activities and have no secrecy. We are the more glad to do this as an example to other laboratories to offer their programs so that there be none of that crime against research —duplication. We do not wish to treat our knowledge as a sentimental treasure rather than as a field of scientific research. The chance of adaptation as well as the opportunity for fresh minds are diminished by the idea that there are professionals in research where all are amateurs as research can never be standardized or confined.

Every director of research knows full well that the productivity of his staff depends upon free and untrammelled

* Presented at the Stated Meeting held Wednesday Dec. 15, 1937.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

creation. He seeks to enlist the interest of his associates, stimulating them to take the initiative, so it is with our staff which has come to realize that self interest, which formerly believed secrecy and isolation to be its safe guard, is more advanced by a successful coöperative attack than by individual credit for some part of an ineffectual and unsolved problem. Collaboration can here display its greatest effectiveness but what is gained in extent must not be lost in intensity.

Coöperation in research has needed experimentation for itself and, with increasing experience and training, this effort at organization has become, in the last year, clarified, simplified and more effective. The heads of departments have taken a larger place in the relation of their own department to the laboratory as a whole. They have assumed more responsibility and been responsible more and more for the coöperation and correlation. At the beginning it really was a question in this type of coöperative research organization whether the unit could grow larger than was possible for the correlating power of one man. However, with increasing experience and the development of trained heads of departments, it is now shown by the results of our laboratories that it is possible for such a type of organization to grow larger, provided the sub-chiefs have the training, experience and aptitude for organizing research workers in groups.

In new ventures for the year we have established a Department of Micro-chemistry under Dr. H. K. Alber. An elaborate technical description of this has been given in the JOURNAL OF THE FRANKLIN INSTITUTE for December 1937. In biochemistry and biological study generally the amounts of material are so small that the ordinary analytical methods are inadequate. A sample of 20 mg. is with us often as much as can be obtained so that micro-chemical methods are really a necessity.

One constantly recurring problem in biochemistry is to determine the chemical composition of a potent biological material of unknown composition, usually an extract or a fraction and most commonly present in very small amounts. For example, in the extract obtained from the liver by Dr. Neale, it was possible to determine the chemical composition and to identify this substance within two days in our new Micro-chemical Laboratory and otherwise we might have

worked upon this for several years without being able to identify it. Our Micro-chemical Laboratory is one of the most complete and efficient of its kind in this country and indeed is much visited by those interested in this subject.

Research is so often centered around a new piece of apparatus which will give accurate results and make possible manoeuvres which were not possible before. One such piece of apparatus is the Beams air-driven centrifuge which will be described later in this text. For biological study and biological fractionation, this centrifuge is exceptional and unique. It fills a place in conjunction with the big Svedberg oil driven centrifuge and indeed the two complement each other. One Beams centrifuge has been run as high as a million times gravity. The highest rotational speed yet obtained has been with an air driven rotor 9 millimeters in diameter, which was capable of turning up to 20,000 revolutions per second. At this speed the centrifugal force on the periphery of the rotor was 7,300,000 times gravity, the peripheral speed of the rotor was 565 meters per second. If it were possible to turn the rotor on its side and start it rolling at this speed it would encircle the earth in 19¾ hours.

These two centrifuges are again complemented by the Tiselius electro-phoretic apparatus which is also described later in the text. With these three pieces of apparatus, it is possible to study biological fluids in a fashion entirely new and with enormous possibilities for discovery of new facts in regard to life and disease.

Another new venture this last year is the establishment of a synthetic chemical laboratory for the production and study of new medicinal chemicals for treatment of disease. This is presided over by Dr. Arthur Binz, late professor of Organic Chemistry at the University of Berlin, who has a long and distinguished record in this phase.

The Cyclotron which at my last report a year ago was under way is now finished and we are beginning the study of induced or artificial radio-active substances as to their effect upon cancer and as a means also of studying metabolism and the distribution of mineral elements in the body by using the activated atoms as tracer bullets or tagged atoms for the radio-active atoms can be traced by Geiger counters or ionization chambers to their ultimate fate in the body.

Our library is increasing in size and fulfilling its purpose well of not only being a depository of information, but of being an educative influence upon the staff as well.

We are about to get out our annual volume of the published papers by the staff of the Biochemical Research Foundation. There will be 33 chapters or papers which have been already published in the respective scientific journals and which will be collected in an edition, limited on account of the expense, and entitled "Reports from the Biochemical Research Laboratories."

Our chief handicap at present is lack of space as we have used up every available square foot of our rented space and, when a new piece of apparatus or new worker requires a place, it means a sort of general post to get the space required.

The general scientific report will now follow and for this I am much indebted to the help and reports of the heads of the departments, Doctors Schroeder, Allen and Ely and to many others of the Staff.

THE CHEMISTRY DEPARTMENT.

In this report will be summarized briefly the various Research Projects now occupying the attention of the Chemistry Staff, explaining at the same time the reasons for our interest in these particular Projects, and what we hope to accomplish in them. The work of the past year will be referred to only in so far as it has a bearing on research now in progress.

Since September 1st, the Chemistry Staff has been increased by five, and now consists of 20 workers. These are, to a certain extent, divided into groups or units, each of which specializes in a given area, as follows:

1. Dr. Schroeder (Chief Chemist).
   Miss Woodward.
   Miss Schoonover.
   Biochemistry of sulfur, with special reference to the role of glutathione in vital systems.
2. Dr. Neale.
   Dr. Outhouse.
   Mr. Winter.
   Fractionation of biological material for isolation of physiologically active substances, with special reference

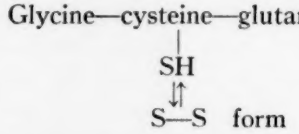
to the liver principle which protects against chloroform, carbon tetrachloride, and other toxic substances.

3. Dr. Elliott.
   Mrs. Elliott.
   The carbohydrate metabolism of normal and tumor tissue as revealed by manometric and chemical studies.
4. Dr. Greig.
   Dr. Munro.
   (Supervised by Dr. Elliott.)
   The use of manometric methods in the testing of various compounds for physiological effects.
5. Dr. Binz.
   Dr. Reinhart.
   Dr. Pence.
   Synthesis of organic compounds of possible medicinal value. Arsenicals; sulfur compounds.
6. Dr. Koets.
   Dr. Christian.
   Colloidal phenomena in vital systems. The Boevenkamp-Kisjes serum cancer test. Studies in coacervation.
7. Dr. Weil.
   Application of the Linderstrøm-Lang micro technique to the study of blood changes (particularly enzymatic) occurring during cancer and other diseases. Study of various blood tests for cancer.
8. Dr. Kocholaty.
   Factors influencing the production of enzymes by bacteria. Formation of specific proteolytic enzymes by bacteria.
9. Dr. Benoy.
   Refinement of analytical methods for use by various members of the Department. Development of a suitable method for glycine estimation.
10. Dr. Alber.
    Dr. Harand.
    Mr. Batt.
    Micro-analytical group. A service Department for the rest of the Laboratory. Development of new micro-analytical procedures.

1. Biochemistry of Sulfur (Schroeder, Woodward, Schoouover).

The primary aim of this Project is to gain information on the role of the naturally occurring sulfhydryl compound, glutathione, in vital systems. Incidentally we hope to gain information on the significance to biological processes of the SH $\leftrightarrows$ SS equilibrium in general (apart from glutathione itself), and of sulfur in other combinations.

Glutathione is a tripeptide, consisting of three amino acids, as follows:



It occurs in all cells as far as is now known. It is easily oxidized by molecular oxygen (in the presence of certain metal catalysts) to the S—S form, which in turn can be reduced back to the original —SH form by nascent hydrogen.

The function of glutathione and of other —SH compounds is not well understood. Among the things we do know about it, the following may be mentioned:

(*a*) Glutathione acts as a catalyst in the oxidation of fats (in vitro). Because of its easy oxidizability and reducibility, it is generally thought to play a part in respiratory mechanisms.

(*b*) Glutathione is a non-specific activator of certain enzymes such as cathepsin and papain. Other —SH compounds also activate these enzymes.

(*c*) According to recent work of Hopkins, glutathione protects vitamin C against oxidation, thus acting as a stabilizer.

(*d*) Glutathione is the specific activator of the enzyme glyoxalase, which may be concerned in lactic acid formation in certain tissues. No other —SH compound activates this enzyme, and the specificity has been made the basis of a specific method for glutathione estimation (Woodward).

Our present work in this field may be summarized as follows:

I. THE PURIFICATION OF THE KIDNEY ENZYME (OR ENZYMES) RESPONSIBLE FOR THE HYDROLYSIS OF GLUTATHIONE.

Several years ago we discovered, in kidney tissue, what we believe to be a new enzyme which rapidly hydrolyzes glutathione. At first we thought that only the glycine portion of the molecule was removed, leaving glutamyl-cysteine in solution. Since then we have shown that both linkages are hydrolyzed, with formation of the constituent amino acids.

Miss Woodward is now engaged in attempting to purify or isolate the enzyme or enzymes involved in this hydrolysis. We want to know whether *one* or *two* enzymes are involved; if two, then perhaps they can be separated, in which case we would be in position to prepare the two sulfhydryl dipeptides, glutamyl-cysteine and cysteinyl-glycine in amounts sufficient for experimental work. The former of these is of especial interest in connection with insulin, which very probably contains a glutamic acid-cystine linkage as one of its active groups.

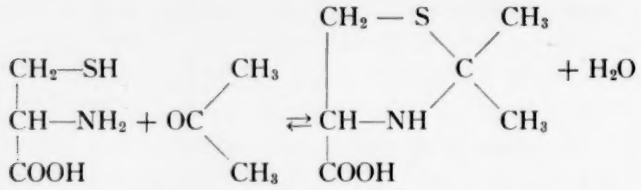
We believe that this new enzyme may play a role in the regulation of the glutathione in tissues, and if it can be sufficiently purified, it may be of use in our experiments on the function of glutathione. Certainly it would be of interest to treat experimental animals with the purified enzyme to see what happens when the glutathione is hydrolyzed, but the $-SH$ group of the cysteine portion remains intact.

In the fractionation work, Miss Woodward is employing the usual procedures, such as precipitation with salts, precipitation with organic solvents, and extractions with water or glycerol under controlled pH conditions. No report is ready on the progress of this work, since considerable time had to be spent in improving the methods for measuring the enzyme quantitatively.

II. THE REACTION OF CYSTEINE AND OTHER SULFHYDRYL COMPOUNDS WITH KETO-BODIES.

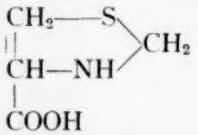
During our studies on the kidney enzyme, we noted that when the glutathione hydrolysis products were titrated by the Linderstrøm-Lang method (with HCl in 90 per cent. acetone),

values much below those expected were obtained. The explanation was finally found in the fact that cysteine, one of the constituents of the glutathione molecule, reacts with acetone very rapidly in the cold, to give the heterocyclic compound, 2,2-dimethylthiazolidine-4-carboxylic acid:

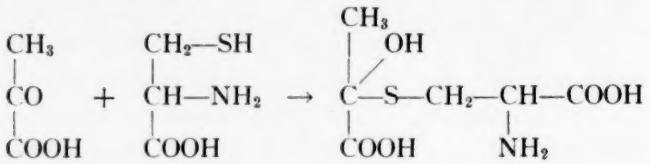


A labile equilibrium is set up as indicated, the extent of condensation depending on the acetone concentration. From mixtures of pure acetone and cysteine, the new compound could be isolated in good yield. When dissolved in water, the compound rapidly dissociated into the original acetone and cysteine.

During the last year, a number of workers have become interested in reactions between sulfhydryl compounds and ketones or aldehydes. Ratner and Clarke prepared the condensation product between cysteine and formaldehyde:



which surprisingly is very stable in water. Two classes of compounds are formed in this type of reaction (1) represented by the ring type of thiazolidine, and (2) simple addition compounds (thio ethers). These latter in general dissociate readily in water. However, we have prepared the addition product between cysteine and pyruvic acid, and it turned out to be quite stable:



A number of other addition and condensation products of similar type have been made, and we plan to study them further. Our interest is not so much in the compounds themselves, as in the possible biochemical significance of the reactions. Since these between —SH compounds and keto-compounds occur so readily at room temperature, it is not at all unlikely that similar reactions may occur in the body. It is conceivable that cysteine, for example, may have a part in the elimination of keto-bodies such as acetone and aceto-acetic acid. It will be of interest to see whether treatment with sulfhydryl compounds will be beneficial in conditions where keto-bodies accumulate, as in the ketosis often associated with diabetes.

III. DETERMINATION OF OXIDIZED GLUTATHIONE.

Oxidized glutathione (GSSG) is usually determined by reducing with zinc in acid solution and titrating the resulting reduced glutathione (GSH) with iodine. We found, however, that in the presence of blood filtrates, only about 20 per cent. of the GSSG present could be reduced with zinc. Other workers had apparently overlooked this fact, and as a consequence, it has been assumed that glutathione exists in blood and tissues almost exclusively in the reduced form (since the oxidized form is not estimated in present methods).

Miss Schoonover has almost completed work on a method which permits nearly quantitative reduction of GSSG in blood. Apparently the substance in blood which prevents the reduction by zinc is a polypeptide of rather low molecular weight. For by using a combination tungstic acid and sulfosalicylic acid reagent to remove the protein prior to zinc addition, good recovery of GSSG results.

This method will be used in the study of the glyoxalase test for cancer. We have been planning to study this test but work on it was delayed until we could get a satisfactory method for GSSG estimation. The test depends on the reaction:

$$\underset{\text{Methylglyoxal}}{CH_3—CO—CHO} + H_2O \xrightarrow[GSH]{\text{Glyoxalase}} \underset{\text{Lactic Acid}}{CH_3—CHOH—COOH}.$$

Addition of cancer serum is believed to inhibit this reaction to a greater degree than does normal serum. This is believed to be due to some factor, present in greater amount in cancer blood, which destroys or in some way inactivates the glutathione.

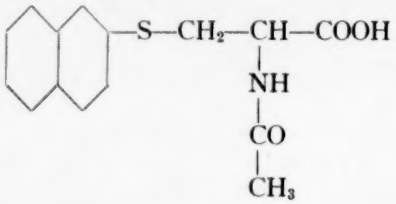
Two other lines of research on which work will be done in the future are:

IV. THE FACTORS WHICH INFLUENCE THE GLUTATHIONE CONTENT OF TISSUES IN VIVO, AND THE PHYSIOLOGICAL EFFECT OF INCREASING OR DECREASING THE GLUTATHIONE CONTENT OF TISSUES IN VIVO.

We plan, for example, to keep rats on a cysteine (and glutathione) deficient diet over extended periods, and then see how greatly the glutathione content of the tissues can be reduced. On the other hand, does feeding or injection of excess cysteine lead to an increase of glutathione in the tissues? Also what effect on the glutathione content would result from injection with compounds which readily react with glutathione, as for example, alloxan, iodoacetic acid, and various arsenoxides? By work along these lines we hope to get a clearer insight into the function of glutathione.

V. THE RELATION BETWEEN SULFHYDRYL COMPOUNDS AND THE CARCINOGENIC HYDROCARBONS.

In the last few years much work has been done on the feeding or injection of certain hydrocarbons, such as benzene, naphthalene and anthracene. Invariably it is found that a large part of these hydrocarbons is secreted in combination with the sulfhydryl compound, cysteine, as a mercapturic acid derivative. For example, with naphthalene we have:



It has been found that feeding of naphthalene to rabbits leads to formation of cataract of the eye. When this occurs, the glutathione and cysteine content of the lens is found to be much reduced. Also, feeding of excess cysteine simultaneously with the naphthalene diminishes the incidence of cataract formation. In other words a relation exists between the hydrocarbon and the $-SH$ groups in cataract formation.

This naturally leads to the question: Is the action of carcinogenic hydrocarbons in any way related to their possible reaction with $-SH$ compounds in tissues? It has in fact been found that the $-SH$ compound, *p*-thio-cresol, when applied to the skin of rats simultaneously with a carcinogenic hydrocarbon, diminishes the incidence of cancer.

It is hoped that this interesting question can be studied in the future.

2. Tissue Fractionation. Anti-necrosis Factor of Liver (Neale, Outhouse, Winter).

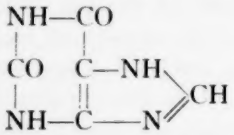
This Project is a continuation of the work which Dr. Neale has been carrying out here for the past year, on the prevention of liver damage from various toxic substances, particularly the chlorinated hydrocarbons such as chloroform, carbon tetrachloride, and tetrachlorethane.

The liver necrosis and fatty degeneration which follows administration (either by injection or by inhalation) of these substances, has been a subject of study by numerous workers during recent years. The subject is of considerable practical importance in connection with the use of chloroform as an anesthetic, of carbon tetrachloride as a vermifuge in hookworm disease, and in the increasing use of the chlorinated hydrocarbons in dry cleaning processes.

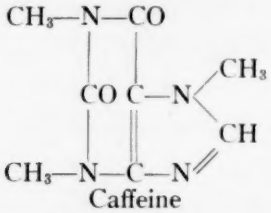
In 1936, Forbes and Neale, working at the Medical College of Virginia, reported on the preparation, from hog liver, of a liquid extract which when injected into rats prior to acute poisoning with $CHCl_3$ or CCl_4, exerted a strong protective action against these poisons.

During the past year, Dr. Neale isolated a crystalline compound from the active hog liver extracts, which likewise had a strong protective action against these poisons. With the aid of our new Micro-chemical Laboratory, this substance

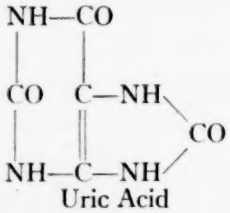
was identified as the purine base, xanthine:



This striking discovery has opened the whole question of the physiological significance of the purines and their derivatives. Not a great deal is known on this subject: we know of course of the diuretic action of caffeine, theobromine, and theophyline, and their action in stimulating brain activity and the strength of the heart beat, but not much more.



Caffeine



Uric Acid

Theobromine: 3,7-dimethyl xanthine
Theophyline: 1,3-dimethyl xanthine

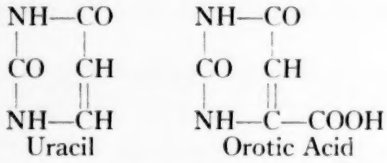
In protecting against liver damage from $CHCl_3$ and CCl_4, the xanthine is administered as the sodium salt. It has certain disadvantages, such as its low solubility and painful reaction on injection, and leaves much to be desired from a clinical standpoint. Because of this fact our program centers to a large extent around an attempt to find other purine derivatives which will be even more active than xanthine, which will be more soluble, and have less irritating effect on injection.

The research program of Dr. Neale's group falls naturally into three lines:

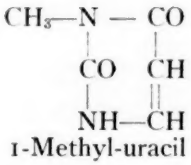
1 (By Mr. Winter). Synthetic work aimed at producing purine and pyrimidine derivatives having protective action and more suited to clinical work than xanthine itself. Mr. Winter has prepared a number of compounds, some of which were previously known but not available on the market, and others are new compounds. As these are obtained, they are turned over to Dr. Neale for animal experimentation. In

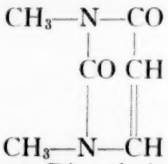
this way we hope not only to obtain better protective substances, but also to obtain information on the relation between structure and physiological activity, and perhaps on the nature of the active group. The compounds will also be tested, when possible, for other physiological effects.

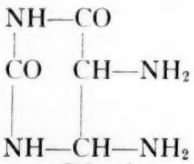
A number of derivatives of uracil have been prepared. Uracil is the pyrimidine portion of the xanthine molecule. In early experiments excellent protective action was obtained by the use of uracil, but later results were not so satisfactory. However, since the synthesis of uracil derivatives is simple compared to that of purine derivatives, Mr. Winter prepared, among others, the following:


Uracil

Orotic Acid

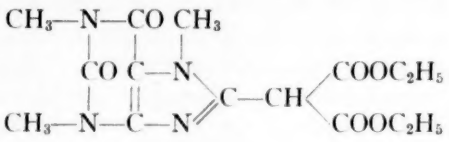

1-Methyl-uracil


1,3-Dimethyl-uracil


4,5-Diamino-2,6-dioxy-pyrimidine

When the pyrimidine derivatives appeared not to be giving the desired results, the preparation of purine derivatives was begun. This is quite a difficult field, and progress has been slow. 8-Methyl-xanthine was prepared by the action of acetic anhydride on uric acid. The methyl group can be brominated and the bromine compound converted into various xanthine derivatives. The particular reaction now under study is the preparation of caffeine-8-malonic ester, and an attempt will be made to demethylate this to yield xanthine malonic ester:

Caffeine Malonic Ester



It will probably not be of general interest to discuss this synthetic work in detail.

2 (By Dr. Outhouse). The chemistry of the poisoning and detoxifying effects.

This work was begun only a few months ago so that few results have been obtained as yet. To date, the toxifying and detoxifying effects have been measured only qualitatively (or roughly semi-quantitatively) by staining sections of the liver and examining them under the microscope. Obviously this method is subject to a large experimental error, and it would be a great advantage to have a method for following the changes which occur in the liver, by means of some chemical estimation. This is what Dr. Outhouse is attempting to do.

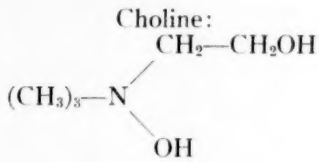
Many people have suggested that possibly the glycogen content of the liver is related to the toxic effect of the chlorinated hydrocarbons. It was claimed that less liver damage resulted when the CCl_4 or $CHCl_3$ was administered to well-fed animals, with high liver glycogen content, than when starved animals were used. We studied the relation between toxic effect and liver glycogen content, but could find no correlation, and so this line was stopped.

In view of the extensive fatty degeneration which occurs in poisoned livers, Dr. Outhouse is now making estimations of the fat content of the livers of treated and untreated animals. He measures

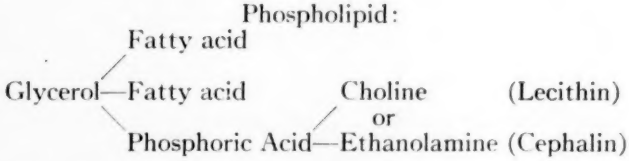
Total lipid.
Total fatty acid.
Neutral fat.
Phospholipid.
Total cholesterol.
Free cholesterol.
Cholesterol ester.

From the work done thus far, it appears probable that phospholipid estimations will be useful in following the extent of liver damage and protection. The phospholipid fraction decreases considerably when the animals are poisoned, but protected animals remain normal in this respect.

Choline:



Phospholipid:



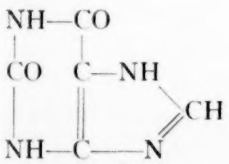
3 (By Dr. Neale). Physiological testing of xanthine and its derivatives.

This phase of the work is, of course, the most important part. Dr. Neale's experiments fall into two general classes:

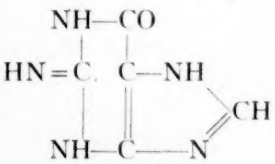
(*A*) The testing of various xanthine derivatives and related compounds for protective action, in an effort to improve on xanthine. Most of this work is being done with CCl_4 and $CHCl_3$ as toxic material.

(*B*) Possibility of protecting against other toxic compounds or toxic conditions of various kinds, by use of xanthine and related compounds.

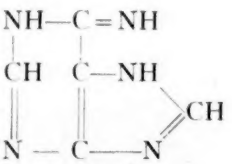
As far as the first part of this work is concerned, it is of interest to note how slight variations in structure will affect protective action. Thus xanthine is



Xanthine

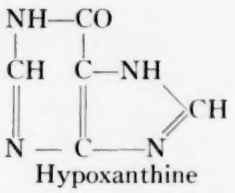


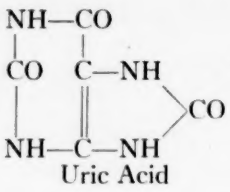
Guanine

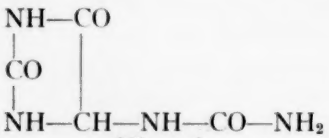


Adenine

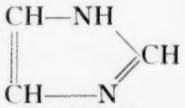
probably the best thus far obtained. Guanine, with only an imino group in place of the oxygen in position 2, gives only moderate protection and is somewhat toxic because of the =NH group. Adenine is very toxic and gives no protection at all.

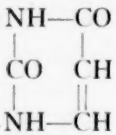

Hypoxanthine

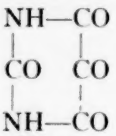

Uric Acid


Allantoin

Hypoxanthine, a reduction product of xanthine, is much less toxic than adenine, and gives fairly good protection, but not as much as xanthine. Uric acid gives some protection. The methylated xanthines, caffeine, theobromine, and theophyline are too toxic for use in the required amounts. Allantoin gives no protection but increases liver damage.


Imidazole


Uracil


Alloxan

Imidazole, which may be considered as a portion of the xanthine molecule, gives no protection, but increases fatty degeneration. Uracil, the pyrimidine portion of the xanthine molecule, as previously stated, at first gave good results especially in the prevention of fatty livers, but failed to live up to early expectations. Numerous derivatives of uracil were tested, but since none was as good as uracil itself, they will all be passed over, except for alloxan, an oxidation product of uracil, which was found to be extremely toxic.

It is probable that xanthine does not occur in the liver in the free state, but in some combination. Attention has therefore recently been directed towards certain of the naturally occurring compounds between purines or pyrimidines and sugars, the so-called nucleosides. Various combinations of these nucleosides, together with phosphoric acid, make up the well-known nucleic acids. Nucleic acid itself

is very toxic but when the animal survives it appears to offer good protection against chloroform poisoning. But a number of other substances are being studied in this general area.

The second part of Dr. Neale's work will be only briefly dealt with, since results thus far are very meager It deals with the possibility of detoxifying other compounds besides chloroform and carbon tetrachloride with xanthine. The following problems are among those under investigation or under consideration:

(*a*) Tetrachloroethane poisoning. This compound has largely replaced carbon tetrachloride as an anthelmintic. It produces liver damage also.

(*b*) Diaminotoluene. Considerable liver damage has been reported among workers handling this compound.

(*c*) Sulfanilamide and prontosil. These new anti-streptococcus germicides have in some cases produced severe after effects.

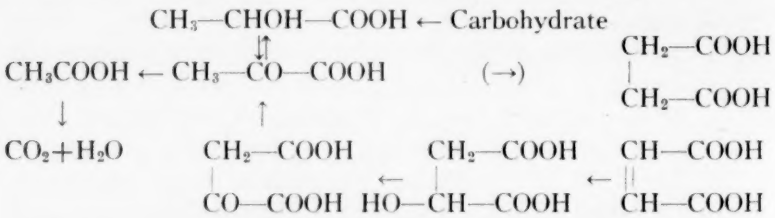
(*d*) X-ray sickness. One theory holds that X-ray sickness is due to a toxemia resulting from tissue destruction. If so, xanthine may be of value. However, more recent work of our own has proven that the lesions produced in X-ray sickness are mainly in the mucosa of the small intestine and not in the liver so that it cannot be expected that sodium xanthine will act as a remedial measure here.

3. Carbohydrate Metabolism of Normal and Tumor Tissue (Dr. and Mrs. Elliott).

Dr. and Mrs. Elliott are continuing the study of the carbohydrate metabolism of normal and tumor tissue, along the general lines followed for the past few years. This work is part of a broad program aimed at elucidating the relation of glycolysis to respiration, the peculiar behavior of tumor tissue, and the difference in glycolysis regulation between normal growing and malignant growing tissue. Fundamentally, this work has its basis in Warburg's discoveries on the high anaerobic, and high aerobic glycolysis (lactic acid formation) of tumor tissue. This tissue, under anaerobic conditions, forms lactic acid rapidly from carbohydrate; in contrast to the great majority of normal tissues, the formation of lactic acid by tumor tissue is not stopped by oxygen (i.e.

tumor glycolyzes aerobically). Hence we believe that a defect exists in the carbohydrate oxidizing mechanisms of tumor tissue. Fundamental studies of the type being done by Dr. Elliott may give information on the exact nature of this oxidative defect, and may suggest remedial measures. Within the last two years, interest in this field has greatly increased, and men such as Green, Krebs, and Szent-Györgyi (the recent Nobel prize winner) have introduced new ideas, so that we can reasonably expect some of these questions to be considerably clarified within a short time.

Dr. Elliott in his first work obtained evidence that in kidney cortex the oxidation of carbohydrate occurred through a cycle of reactions involving lactic, pyruvic, succinic, fumaric, malic, and oxalacetic acids. Further work during the past year has tended to confirm these ideas (with some modification) so that the cycle may be represented as follows:



This appeared to be the oxidative cycle for normal tissues. Tumor was next studied and it was found that certain of these steps did not take place in this tissue:

Lactate → Pyruvate (slowly)
Succinate → Fumarate
Malate → Oxaloacetate

In order to determine whether the oxidative failure in the above steps was specific to tumor tissue, Dr. Elliott then investigated certain other normal tissues such as liver, brain, and testis. A vast amount of data on the behavior of these tissues were accumulated. The chief point that emerged from the work was that the fate of added lactic or pyruvic acid varies strikingly from tissue to tissue. Each tissue seems to have its own peculiarities as regards the oxidation of the above compounds, some steps of the cycle being inhibited in liver, others in brain or testis.

The most striking result obtained, as far as tumor tissue is concerned is that this tissue is the only highly respiring one so far found that can metabolize carbohydrate without the intervention of the reaction:

Succinic acid $\rightleftarrows$ Fumaric acid.

It is planned to study a number of other tissues in the same way, particularly retina, which like tumor has a high aerobic glycolysis.

The lack of succinic acid oxidation in tumor tissue appears to be of importance, and further work is being done on it. Also the system: Malate $\rightleftarrows$ Oxalacetate is assuming increasing importance. Recent work indicates that these two systems, with their essential enzymes and co-enzymes, may play the part of respiratory or oxidation catalysts in cellular oxidations and reductions.

To give an idea of the complexity of events, the above two catalytic systems may be represented as follows:

$$H_2 + \begin{matrix} CO{-}COOH \\ | \\ CH_2{-}COOH \\ \text{(Oxaloacetate)} \end{matrix} \xrightarrow[\text{Dehydrase}]{} \begin{matrix} HO{-}CH{-}COOH \\ | \\ CH_2{-}COOH \\ \text{(Malate)} \end{matrix} + \text{Co-enzyme I} \xrightarrow[\text{oxidase}]{\text{Co-enzyme}} O_2$$

$$H_2 + \begin{matrix} CH{-}COOH \\ \| \\ CH{-}COOH \\ \text{(Fumarate)} \end{matrix} \xrightarrow[\text{Dehydrase}]{} \begin{matrix} CH_2{-}COOH \\ | \\ CH_2{-}COOH \\ \text{(Succinate)} \end{matrix} + \text{Cytochrome} \xrightarrow[\text{Oxidase}]{\text{Cytochrome}} O_2$$

For example when lactic acid is to be oxidized to pyruvic acid, the enzyme lactic dehydrase activates the two hydrogen atoms on the middle carbon. These are accepted by the oxaloacetate, which is reduced to malic acid. Malic acid in turn yields two of its hydrogens to co-enzyme I, and is oxidized back to oxaloacetate. The reduced co-enzyme I is then oxidized by molecular oxygen under the influence of the co-enzyme oxidase, so that the cycle can start over again. The same cycle occurs in the fumarate-succinate system, except that here cytochrome, instead of co-enzyme I, acts as hydrogen acceptor.

It is believed that perhaps some imbalance in these two catalytic systems may account for the high aerobic glycolysis of cancer tissue, and for this reason further work of a fundamental nature is being done on these questions.

4. Pharmacological Studies by the Manometric Method (Drs. Greig and Munro).

The manometric technique, particularly the Dixon-Keilin modification, has been of much value in the study of the mechanism of carbohydrate metabolism in slices of living tissue. It is also of value in studying the effects which various compounds have on the processes of glycolysis, respiration, and respiratory quotient of tissues. During the past few years, for example, we have studied the effect of oxidation-reduction dyes, iodoacetic acid, fluoride, glyceraldehyde, glutathione, ascorbic acid, xanthine, pyridine, and many other substances.

This year Drs. Greig and Munro are extending this work. It has long been our aim to determine whether this technique could be used for *in vitro* pharmacological testing, prior to use of the compounds on animals. If this were possible, one could rapidly test a large number of compounds in the manometric apparatus, and then select the more promising for animal experimentation. A large saving in time and expense would result. In the manometric method one works with thin slices of living tissue and it may be looked upon as being intermediate between animal experimentation and *in vitro* experimentation with enzymes in tissue extracts. Of course, since the slices are removed from the influence of the rest of the organism, the effects observed may vary considerably from those observed in the living animal.

One difficulty is that the manometric method measures only certain phases of carbohydrate breakdown, namely, glycolysis, respiration, and respiratory quotient. It tells little about other metabolic events, such as protein or fat metabolism. Therefore it is likely that the method will give information of value only in so far as it relates to carbohydrate metabolism. An example of a field in which results might be expected is the attempt to influence the abnormal carbohydrate metabolism of tumor tissue toward a more normal course, by means of various organic compounds. Cancer has

both high aerobic and high anaerobic glycolysis. Substances are known which influence these activities in the direction of a more normal metabolism. Our hope is that we shall find compounds which will reduce the high aerobic glycolysis of tumor tissue, not only *in vitro* but also *in vivo*. Whether such compounds will be of any value in the treatment of cancer remains to be seen.

Drs. Greig and Munro are doing work, or contemplating work, along the following lines, among others:

(*a*) A series of some 25 organic arsenic compounds, prepared by Dr. Binz, is being tested. The relative toxicity of these compounds towards rats or mice has been determined, and it is planned to see whether any correlation exists between toxicity and effects of metabolism.
(*b*) Other compounds (not arsenicals) now being prepared by Dr. Binz, will be studied in the same way.
(*c*) A study of the effects of certain cellular constituents believed to play a part in respiratory or glycolytic processes. Among these are co-enzyme I, cytochrome, and succinoxidase.
(*d*) Pyrophosphate. Preliminary studies indicate that $M/100$ pyrophosphate causes a considerable increase in the respiration, and a fall in the respiratory quotient of kidney and tumor slices.
(*e*) Various hormones, including insulin and adrenaline. In preliminary experiments adrenaline caused an acceleration of respiration.

Results cannot yet be reported in detail. It often happens that one type of tissue will respond in one way to a given compound, and a different tissue in an entirely different way. This means that each compound may have to be tried on a variety of tissues. Also the concentration of the compound is an important point. High concentrations may give one result, and low concentrations another. It may therefore be necessary to run experiments at various concentrations also.

5. Synthesis of Organic Medicinals (Drs. Binz, Reinhart, and Pence).

Last September we established a laboratory devoted to the synthesis of new organic compounds of possible thera-

peutic value. This represents our first extensive effort in the field of synthetic chemistry. Dr. A. Binz came from the University of Berlin to assume charge of this work, and he now has two assistants, Dr. Reinhart and Dr. Pence.

The decision as to the particular compounds to be synthesized is, of course, always a difficult matter in this type of work. It is generally impossible to predict whether a given compound will have any beneficial therapeutic effect. A good example of this is sulfanilamid, the new remedy for hemolytic streptococcus infections, which has been known for years, but was never suspected of having valuable medicinal properties. The most one can do, therefore, is to select compounds analogous to those which have been shown to be effective.

Among the lines now being followed by Dr. Binz, the following may be mentioned:

A. Sulfur compounds. Various types of sulfur compounds have been shown to be quite effective germicides. They have also been used with some success to stimulate healing of wounds, and in the prevention of tar cancer. It is hoped that further studies will reveal compounds of greater value than those available now.

B. Arsenic compounds. There is considerable room for improvement in the arsenicals now being used.

C. Selenium compounds. These have been used with some success in the treatment of cancer. It is planned to prepare selenium compounds analogous to the above-mentioned sulfur compounds.

The difficult part is the testing of the new compounds for physiological activity, and this part of the program is still in a developing stage. Our plans call for rather comprehensive tests, not only on experimental animals but also by *in vitro* methods. We plan to subject the compounds to the following procedures:

(*a*) Physical effects (lysis, etc.) on cells—blood cell suspensions and single-celled organisms.

(*b*) Manometric studies on tissue slices for effects on metabolism.

(*c*) Bacteria—phenol coefficients for bactericidal action. Effects on growth, etc.
(*d*) Animal experimentation—toxicity—effects on organs—use in induced diseases.
(*e*) Humans—clinical testing.

By doing a variety of tests of this sort, we hope to increase the likelihood that possible beneficial effects will not be overlooked.

6. Colloidal Phenomena. Chromate Cancer Test (Drs. Koets and Christian).

Dr. Koets and Dr. Christian have taken up the detailed study of the Boevenkamp-Kisjes serum test for cancer. In this test, sodium chromate is added in increasing amounts to serum, the pH being kept constant (3.6–3.8) by addition of appropriate amounts of propionic acid. This is done first for the fresh serum, and then with serum which has been heated to 56° for 30 minutes. The heights of the protein precipitates obtained are measured in each case, and graphs are made by plotting concentration of chromate against height of the pricipitate. The curves fall into three groups: (a) Normal serum. Here the two curves obtained with heated and unheated serum run practically parallel and do not intersect each other except occasionally at quite high chromate concentrations. (b) Serum in disease, excepting cancer. In this case the two curves generally intersect each other, but only at quite high chromate concentrations. (c) Cancer serum. Here intersection of the two curves occurs at very low chromate concentrations. The distance between the first precipitate and the intersection is the decisive factor. If it corresponds to less than 0.375 millimol of sodium chromate, the authors consider the reaction positive for cancer.

The results obtained by the original authors were quite promising, and we decided to see how the test would work in our hands. Considerable difficulty was experienced at first in getting accurate measurements on the height of the precipitates, and efforts are now under way to develop a turbidimetric method for measuring the precipitated protein. Considerable trouble was also experienced in controlling the pH properly. The reaction seems to be quite sensitive to

change in external factors, and much care must be taken to perform the test under proper conditions. Most of this preliminary work has been done on animal serum, since large amounts were needed. We expect later to see if the test will be obtained also in experimental rat cancer. If, under proper conditions, the test can be obtained here, this will be a convenient source of material for studying the reaction. It will be of interest, for example, to determine at what stage of the cancerous growth the test first appears.

Dr. Koets has made an analysis of the results obtained thus far in our Laboratory on human cancer patients. If we take 0.375 millimols Na_2CrO_4 (difference between start of precipitation and intersection) as the dividing line between normal and cancer, then we find:

Diagnosis +	Δ under 0.375	27 cases
33 cases	Δ over 0.375	6 cases
Diagnosis —	Δ under 0.375	2 cases
22 cases	Δ over 0.375	20 cases

When the results are plotted, there is a quite sharp separation between the majority of the cancer cases and the majority of the normals. However, there is some overlapping. In general it may be said that these results compare favorably with those of other tests, although they leave much to be desired.

A study of cancer tests is of value not only for the purpose of developing improved methods of diagnosis. A study of the reasons for the existence of such differences as appear between cancer and normal sera in this test may throw light on some aspect of cancer chemistry. It is this second phase that particularly interests Dr. Koets. The originators of the test suggested that the proteins in cancer serum may possess a different adsorption power for electrolytes than do proteins of normal serum, and heating has the effect of making this difference more pronounced. Dr. Koets does not accept this explanation. He feels that it may be due to a difference in the serum lipids (fatty material), rather than to a difference in proteins. He points out that the phospholipid, lecithin, can alter its protective power for proteins on heating, and it may be that differences in cholesterol or lecithin content

of the blood may be responsible for the differences between cancer and normal serum.

Many previously proposed tests for cancer which were based on altered protein properties, have proved to be unspecific for cancer, and to give positive tests in all diseases in which the protein balance of the serum is upset. If the chromate reaction depends on lipid change in serum, it may prove to be more specific than other tests.

It is planned also to replace the chromate ion with other polyvalent anions. One now being studied is a complex organic sulfonate, Germanin, which gives a hexavalent anion in solution.

Later Dr. Koets intends to study certain biological implications of the colloidal phenomenon known under the imposing title "coacervation" which means the reactions of colloids in combinations, as these are different from reactions of the pure colloids alone. In the body, colloids are always in combination so that the reactions in combination must be studied.

7. Use of the Linderstrøm-Lang Micro Technique in Cancer Blood Studies (Dr. Weil).

During the past several years, Dr. Weil has been engaged in histo-enzymatic studies on various tissues, chiefly kidney, using the new Linderstrøm-Lang micro technique for determining enzyme activity in very thin sections of tissue. This technique has for its aim the correlation of the histological picture of the tissue with the activities of particular enzymes. By this means evidence can be obtained as to the location, in the tissue, of the enzymes in question. In the kidney work, it was expected that such information would ultimately lead to a better understanding of the mechanism of certain kidney functions, especially those involving enzyme action. Such knowledge might be of value in the study of certain kidney disorders.

When making up our program for the present year, it appeared to us that, however interesting such studies might be from the purely scientific viewpoint, little of immediate practical value would result from this type of kidney work for a long time to come. Various other problems were considered, among them a study of the enzymes of the organs of internal secretion.

The choice finally fell to the application of the micro technique to a study of blood changes occurring during the development of rat cancer, and in other diseases. Our aim here is not only to secure fundamental knowledge of the chemistry of cancer (and other diseases) but also, if possible, to develop new and better methods for cancer diagnosis.

Our work at present is confined to transplantable rat cancer. The question is often raised as to how far results obtained on animal cancer are applicable to human cancer. This is, of course, a valid question, which until now cannot be answered. There are, however, certain advantages in working with animal cancer. Many studies have been made on the blood constituents in human cancer, as compared to normal. These have in general not yielded much information of value. We believe that this may be due in large part to the difficulty of controlling human subjects. The blood is a very labile system, and factors such as diet and treatment, which probably influence the blood to a high degree, cannot be adequately controlled for this type of work in humans. Also in human cancer it is almost impossible to study the blood except in relatively far advanced cases, so that the early stages are missed.

With this in mind, we turned to cancer rat blood. Here is a source of material which can be quite accurately controlled with respect to diet, age of cancer, treatment, and other factors. The general plan is to follow the blood changes of individual rats throughout the entire course of the disease. Since the blood supply of the rat is limited, we must use micro methods, and the Linderstrøm-Lang technique is admirably suited. The technique is as follows: Immediately after inoculation of the cancer, a 1 millimeter section is cut from the end of the tail, and a drop of blood is squeezed out on a depression slide and analyzed for the particular constituent of interest at the moment. At 3 or 4 day intervals this operation is repeated, so that we have a complete record of an individual rat from the beginning of the cancer growth until death. One drop of blood is sufficient, in the micro technique, for several different determinations. One can work with whole blood, or by centrifuging in capillary tubes, with cells and plasma separately.

The actual experimental work done thus far has been confined largely to working out the technical details involved in handling such small amounts of blood, and in studying some of the characteristics of the blood enzymes. A knowledge of the pH optimum, activation behavior, and the relation between enzyme quantity and activity, is necessary for each enzyme before quantitative measurements can be made. The only enzyme studied systematically thus far in cancerous rat blood is the proteolytic enzyme, aminopolypeptidase. In a 4-week period during the growth of Phila. No. 1 sarcoma, no changes in the activity of this enzyme were noted.

Our program calls first for a comprehensive study of the proteolytic enzymes in the blood. The considerable protein synthesis and degradation which must occur during development of cancer, should lead to changes in the proteolytic enzyme system of the blood. In addition to the above-mentioned enzyme, we plan to study dipeptidase, carboxypolypeptidase, and proteinase. Later the fat-splitting enzymes, the lipases, will be taken up. Some evidence already exists that a considerable change in the latter occurs, particularly in cancer produced by carcinogenic hydrocarbons. Some years ago Koehler and Schoonover, in our Laboratory, obtained evidence of possible changes in the enzyme phosphatase in human cancer blood. This enzyme will also be studied by the new technique.

The Linderstrøm-Lang technique is adaptable to the determination of various non-enzymatic constituents as well, such as sugars, ascorbic acid, chloride, etc. One of the phases of our work is the extension of the technique to the determination of other substances. As these methods become available, they will also be applied in these blood studies.

As previously stated, one of the aims of this work is the development of new blood tests for cancer. In this connection may be mentioned two rather well-known blood tests for cancer which apparently depend on enzyme action: (1) the Fuchs tests and (2) the Shaw-Mackenzie test. It is not known whether these tests are obtained in cancer *rat* blood, but we shall try it, and if we can obtain it, we shall be in position to study the factors influencing them.

The Fuchs test has proved highly successful in many

hands. It apparently depends on the fact that plasma proteinase (proteolytic enzyme) is able to decompose only "Art fremde" or "foreign" protein, but not protein from its own host. If we prepare normal and cancer plasma protein, then add to each some serum from a cancer patient and serum from a normal, we shall have (+ denotes digestion):

	Normal Protein	Cancer Protein
Normal serum	−	+
Cancer serum	+	−

Normal serum enzyme will decompose cancer protein but not normal protein, while the reverse is true for the cancer serum enzyme.

The Shaw-Mackenzie test depends on the fact that normal serum activates pancreatic lipase (fat-splitting enzyme) to a greater degree than does cancer serum. Nothing is known of the mechanism of this reaction.

8. Factors in the Production of Bacterial Enzymes (Dr. Kocholaty).

This Project is an outgrowth of our work on the bacterial filtrates developed for cancer treatment. In the early stages of that investigation, it was believed that the active principle was a proteolytic enzyme, specific to cancer protein, which was secreted by the microörganism *Cl. histolyticum* when grown on a cancer tissue medium. This idea of the enzymatic nature of the active principle is no longer accepted, but certain principles are still valid.

Our general problem is to study the factors which influence the production of proteolytic enzymes by bacteria, the properties of these enzymes and how affected by changes in the culture medium, and finally, the possibility of training the bacteria to produce proteolytic enzymes which are specific to particular proteins.

The micro-organism at present under study is the strongly proteolytic anaerobe, *Cl. histolyticum*. When this bacterium is grown on the usual nutrient media, it produces a highly active proteolytic enzyme, which apparently is secreted by the living cell into the surrounding medium. The hypothesis is that when the organism is inoculated into a medium containing chiefly protein, and very little of protein degradation products (such as amino acids or polypeptides), then before

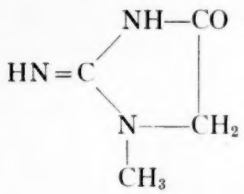
bacterial growth can take place, the bacteria must secrete a proteolytic enzyme which can hydrolyze the protein molecules into smaller fragments which are able to penetrate into the cell and serve as food material for growth. By subculturing repeatedly on a given pure protein medium, we hope to develop the bacteria to a point where their secreted enzyme is specific toward the particular protein in question, and will not attack other proteins. If this can be done, then the next step might be to apply the same technique to tissue proteins derived from various organs, and to cancer proteins. Perhaps in this way it might be possible to develop cancer-specific enzymes.

A number of facts lead us to believe that the matter is worth following up:

(1) As previously stated, the Fuchs cancer test apparently depends on the presence in normal serum, and absence in cancer serum, of a specific cancer-protein hydrolyzing enzyme. If this interpretation of the test is correct, then the body is able to synthesize cancer-specific enzymes, and the same may be true of bacteria under proper conditions.

(2) Dubos has shown that by growing a certain microörganism on a medium containing the polysaccharide of type III pneumococcus as sole source of carbon, an enzyme is produced which specifically attacks only that polysaccharide, and not those of types I or II pneumococcus. Highly favorable results have been reported on the use of this enzyme in treating animals infected with type III pneumococcus. The same principle should operate also in the field of proteolytic enzymes.

(3) Dubos has recently shown that a certain microörganism isolated from soil, when cultured on a medium containing creatinine as sole source of carbon, produces an



Creatinine

enzyme which hydrolyzes creatinine with a high degree of specificity. Many other compounds closely related to creatinine were not attacked. Dubos has made use of the new enzyme in establishing definitely the presence of creatinine in blood.

In general it appears that bacterial enzymes fall into two broad classes: the so-called "constitutive" enzymes which are formed by the cells irrespective of the medium in which they are grown, and the "adaptive" enzymes, which are formed only as a response to the presence of a definite substrate in the medium. It is this second class in which we are interested. It is quite likely that when proper methods and techniques have been developed, we may be able to produce enzymes with a proper degree of specificity, adapted to the hydrolysis of many types of organic compounds.

Attempts to produce specific enzymes have not yet begun. The work to date has been confined, rather, to a study of the properties of the secreted enzymes obtained under varying experimental conditions. It was found, for example, that when *Cl. histolyticum* is grown on a horse meat medium, the amount of enzyme present increases to a maximum at about 24 hours and then falls sharply. The bacterial count parallels the enzyme activity. But the aminopolypeptidase activity (as distinguished from proteinase activity) increases slowly with time throughout the course of the experiment. This enzyme is concerned in breaking down polypeptides of low molecular weight, and is probably liberated from the cell only after autolysis. We do not yet know the reason for the sharp drop in proteinase activity after 24 hours, but studies on this point are in progress.

Other studies include the effect of the nature of the medium on the enzyme properties (pH optimum, activation behavior), effect of pH of the medium, effect of addition of growth promotors on enzyme production, etc. In other words, we are getting information on the properties of the enzymes produced, and the effect of changing experimental conditions on those properties. In addition to the proteinase, studies are made on other proteolytic enzymes, such as amino- and carboxy-polypeptidase and dipeptidase.

9. Development of Analytical Methods. Estimation of Glycine (Dr. Benoy).

During the past two years, Miss Benoy has collaborated with Dr. Elliott in his studies on carbohydrate metabolism. Her part of the work was the analytical determination, by chemical means, of lactic acid, pyruvic acid, glycogen, and other compounds involved. When this phase of the research was brought to a conclusion, we decided to make further use of her experience and ability as an analyst.

In biochemical work, one of the great difficulties always is the lack of suitable methods for the accurate estimation of various biological compounds. Often, in initiating a new research, we expend a large amount of time and energy in developing analytical methods before actual work on the main problem can be started. Miss Benoy was therefore assigned to the task of coöperating with others in the Department in developing suitable methods when required. This does not conflict with the Micro-analytical Department. It refers rather to the development of macro or semi-micro methods which are to be used routinely by members of the research Staff themselves.

Miss Benoy's present work is the development of a suitable method for estimating the amino acid, glycine, in the presence of glutathione and its hydrolysis products. There is a need for such a method in our study of the hydrolysis of glutathione by kidney extracts. Some years ago Patton described what he claimed to be a specific colorimetric method for glycine. It depended on the development of a bright green color with the reagent, *o*-phthallic dialdehyde. In our hands the method proved anything but specific, a variety of colors being obtained with different amino acids. Particularly in hydrolyzed glutathione solutions, an intense blue color was obtained with the reagent.

Miss Benoy found that this blue color was due to the simultaneous presence of glycine and the $-SH$ amino acid, cysteine. Efforts were made to remove the cysteine prior to addition of the color reagent, by oxidizing it to insoluble cystine, or by treating with iodoacetic acid, which reacts with the $-SH$ group. These methods were troublesome and not very accurate, because some cystine always remained in solution and also interfered with the color test.

Lately some measure of success has been obtained by precipitating both cysteine and cystine with mercuric sulfate in highly acid solution. In 0.1 N acid, these amino acids can be quantitatively precipitated with the mercury reagent, while glycine remains in solution. The excess mercury is removed with H_2S and the resulting filtrate treated directly with the color reagent.

One of the great needs in biochemistry is the development of specific methods for determining all the individual amino acids. It may be possible, by applying the above mercury technique under proper pH control, to separate individual amino acids from each other, or at least to separate them into definite groups.

THE PHYSICS DEPARTMENT.

It is the object of this report to summarize briefly the various research projects now occupying the attention of the Physics Staff, explaining at the same time the reasons for an interest in these particular projects and what we hope to accomplish in them.

The Physics Staff consists of five workers and these can, to a certain extent, be divided into groups or units, each of which specializes in a given area, as follows:

1. Dr. Allen.
   Dr. Sampson.
   The construction and development of the cyclotron for the production of neutrons and artificial radioactive substances. This work is being done in coöperation with the Bartol Research Foundation.
2. Miss Franklin.
   Ultraviolet absorption spectra, ultraviolet photomicrography. Standardization of radiation effects on living organisms, this work being done in coöperation with Dr. Mundell of the Cytological Department.
3. Mr. Dietz.
   The electrical characteristics of erythrocytes, Tiselius electrophoresis apparatus and its applications, and fractionation of biological solutions by use of the Beams air-driven ultracentrifuge. This work is being done in coöperation with Mr. Smith of the Cytological Department.

4. Dr. Sanigar.
   Dr. Krejci.
   Studies on large molecules with the Svedberg ultracentrifuge (using the ultracentrifuge of the du Pont Experimental Station). More specifically, the effects of radiations on human blood serum and the distribution and identification of protein molecules in normal and pathological serum.

1. The Construction and Development of the Cyclotron for the Production of Neutrons and Artificial Radioactive Substances.

The primary objective of this project is to obtain an intense source of neutrons and artificial radioactive substances to be used for experimental therapeutic purposes. A second use which may eventually be more important than the primary will be the use of these artificial radioactive substances as biological and chemical indicators. Preliminary work with neutrons on various biological entities has been reported in the literature. This work tends to prove that the biological effect of neutrons as compared to X-rays is not linear. That is, the ratio of the amount of X-rays to neutrons required to kill five biological entities varies from 2.5 to 5.1, the ratio of 5.1 being that for mammary carcinoma. These experiments indicate that this mammary carcinoma is much more susceptible to neutrons than is normal tissue.

It is quite possible that artificial radioactive substances will entirely supplant the natural radioactive substances, that is, radium, in the treatment of cancer. The possible advantages of the artificial radioactive substances are as follows: (1) Most of the elements in the periodic table have already been made radioactive; therefore it will be possible to choose the chemical characteristics that may be desirable for introducing the radioactive substances into the desired locality in the animal. (2) The half-life of the artificial radioactive substances is short compared to that of radium. The action of the substances, therefore, can be intense and of short duration. (3) The disintegration products of radium and radon are very harmful to the system, whereas most of the end-products of the artificial radioactive substances are practically inert. In fact, radioactive sodium chloride has

already been introduced into the blood stream as a treatment for leukemia. (4) With the natural radioactive substances only the gamma rays are used, the alpha and beta rays being screened out usually by gold or platinum filtration. The alpha and beta rays are however the most biologically active or potent in destroying cells. By introducing a solution of the artificial radioactive substances which have no toxic after-effects, it is not necessary to screen out the alpha and beta rays and thus more of the desired action is produced.

The use of artificial radioactive substances as biological indicators has also been reported in the literature from time to time. Considerable work has been done in determining the fate of calcium and phosphorus. This technique is quite simple, and as soon as biologists and chemists learn of its simplicity they are very eager to work with the substances.

The cyclotron in its present stage can be compared to the automobile of 1904. It is not a reliable, fool-proof machine and is subject to frequent breakdown, and improvements in design and operation technique are made constantly. It will be necessary to incorporate the latest developments in our machine, especially in our case where large amounts of radioactive material will be needed. We hope therefore always to have a first-rate cyclotron and to discover its possibilities for the treatment of cancer and for use in biochemical research problems.

2a. Ultraviolet Absorption Spectra.

The process of recording the ultraviolet absorption spectrum of a given compound may be compared to the finger-printing of a person. It is a means of identifying a compound and comparing it with another compound. This apparatus is therefore of considerable value in any biochemical research laboratory and is available to all members of the staff.

b. Ultraviolet Photomicrography.

In our laboratory there is available an excellent all-quartz photomicrographic apparatus for taking photomicrographs with various wave-lengths of ultraviolet light. The apparatus has a theoretical resolving power of 2.5, which is far greater than any existing glass microscope. It is also valuable in

studying the effects of monochromatic ultraviolet radiations on living organisms and considerable work is being done with this apparatus along these lines.

c. Standardization of Radiation Effects on Living Organisms.

Miss Franklin and Dr. Mundell have been studying the effects of carefully measured doses of X-rays on cancer tissue and on the whole of living mice. The irradiated tissues have been sectioned and examined microscopically with both the ultraviolet and visible microscopes, a pathological diagnosis of all the organs having been made. The primary purpose of this work is to study the effects of X-rays, so that the action of neutron rays which will come from the cyclotron may be compared with those of the X-rays. The importance of this work has been recognized by the granting of the sum of thirty thousand dollars by the Government Cancer Committee to do researches along these lines.

3a. The Electrical Characteristics of Erythrocytes.

Mr. Dietz has done considerable work on the electrical characteristics of erythrocytes, with the view of being able to determine differences in normal and pathological erythrocytes. This work has been temporarily discontinued in favor of (3*c*) below.

b. Tiselius Electrophoresis Apparatus (Mr. Dietz).

A Tiselius electrophoresis apparatus has been ordered from Dr. Svedberg's laboratory in Sweden. This apparatus will be used to supplement the work in (3*c*) and (4). It is to be used as a tool for fractionating the large molecular constituents of biological solutions and for determining the number of large molecular constituents present in a biological solution.

The moving boundary method of studying electrophoretic mobilities of ions was devised by Lodge in 1886, when he studied the movement of an interface between two sols under the influence of an electric field. The most recent apparatus developed in the field is that of Tiselius, a colleague of Svedberg.

The apparatus of Tiselius is designed particularly for the

separation of molecules possessing different quantities of the same electric charge. Normally, with the older type of apparatus, after the electric potential had been applied for a certain time, the migrating ions would move to the end of the electrophoresis cell and collect there, even though the ions did not all possess like quantities of the given charge.

In Tiselius' apparatus, however, these moving ions are maintained in the middle of the cell by a compensating movement of the suspending medium in the opposite direction; a condition which may be likened to a man walking on a treadmill who progresses along the treadmill flooring but stands still with respect to the ground. If we carry this analysis a bit farther, it can be seen how the separation of molecules with different quantities of like charges is achieved in the Tiselius apparatus. Suppose our treadmill is large enough to allow two men to move freely on it. If one of them is capable of walking in the same direction but slightly faster than the other, they will in walking be separated from each other, even though they remain on the treadmill because its motion opposes theirs. After charged components of a fluid are thus separated in the Tiselius apparatus, they can be retrieved from different portions of the electrophoresis cell for chemical analysis or biological assay.

It is possible to observe this entire movement over a period of time by a specific optical apparatus, even though the components cannot be distinguished from each other by the naked eye. A most interesting study with this apparatus has been published by Tiselius in which he evaluated the separation of various components of normal and immune blood sera. His work correlated beautifully with the observations of his colleague Svedberg, whose studies were made with the analyzing ultracentrifuge.

c. Beams Air-Driven Ultracentrifuge.

Work has been in progress on the Beams air-driven centrifuge which has been installed in our laboratory. The purpose of this apparatus is to fractionate large molecules which are usually present in biological solutions. At present the apparatus is being used to separate and concentrate various biological fluids. This apparatus is of value in separating

any molecules having differences in molecular weights. Dr. Beams has been successful in using one of these centrifuges to concentrate the two isotopes of chlorine, the mass differences in this case being that of two hydrogen atoms. Dr. Beams is developing a centrifuge of this type for continuous separation of molecules having a slight difference in molecular weights. We are keeping in close touch with this development, for it promises to be of great value in the separation of biological materials.

Ultracentrifuges are divided into two types, the analyzing ultracentrifuge and the quantity ultracentrifuge. The former apparatus is designed so that the movement of molecules in a liquid, subjected to intense gravitational fields, may be continuously observed, and from the data on sedimentation it is possible to arrive at a measurement of molecular sizes of the various components.

The quantity ultracentrifuge is designed for handling large quantities of fluids and obtaining various fractions of them for chemical analysis. The material to be centrifuged is placed in celluloid tubes which are in turn placed in recesses in a duralumin centrifuge head. The head is sealed vacuum-tight, since it must spin in a vacuum so that the high speed of rotation will not cause heating of the rotor due to air friction. The centrifuge rotor is spun up to speed by an air-driven turbine from which the rotor is suspended. While the system is rotating it rides entirely on a bearing of air so that rotational friction is reduced to a minimum. The particular centrifuge head which we are using turns up to a speed of 500 revolutions per second; from three to five hours of centrifuging are required in the normal run, at the end of which time the rotor is brought to a stop and the fractionated samples are removed for analysis.

By slightly decreasing the size of the rotor used it is possible to speed the system up to 1,000 revolutions per second with a fair degree of safety. If the apparatus is rotated at too high a speed the cohesive forces in the metal of the rotating head are overbalanced by the centrifugal force and the rotor explodes.

We have found the apparatus extremely useful in immunochemical studies, and while data obtained in these studies

are not yet in publishable form, we expect that the apparatus will have justified itself within the next three months.

4. Studies of Large Molecules with the Svedberg Ultracentrifuge.

This apparatus more or less supplements the work in (3*b*) and (3*c*). Its chief value, however, is not for making actual separations of the biological solutions but rather for determining the molecular weights of the constituents present in a solution, or for determining the homogeneity or heterogeneity of a biological solution. At the present time a study of the effects of ultraviolet rays and X-rays on human blood serum is being carried on. This sort of work is of interest for it has been recently reported in the literature that the distribution of proteins in normal and pathological serum is different. Also Dr. Svedberg has been able to determine the size of the molecules with which the antigen properties of the blood serum are associated. It is with a view of being able to do work of this kind that this project is being carried on.

THE CYTOLOGY DEPARTMENT.

1. Histochemical Investigations of Cell Nuclei (Dr. Kelley).

This work consists of a histochemical study of sections of rat cancer and other tissues and a chemical study of the nucleoproteins obtained from the cell nuclei of these tissues. The object of the work is to determine the chemical nature of the cell nucleus in both resting and mitotic stages, and to determine differences in the nuclei of different tissues. One aim is to try to determine changes in the chemical nature of the nucleus in pathological tissues such as carcinomatous and sarcomatous tumors as compared with the normal tissues from which they arise.

The investigation is carried out in two ways: Pieces of rat carcinoma and sarcoma tumor, thymus, liver, kidney, spleen and other tissues are fixed in alcohol and other histological fixatives of known chemical activity and prepared as paraffin sections. These sections are stained at 0.2 pH intervals from pH 2 to 7 to determine the point at which basic dye staining of the chromatin of the cell nucleus begins and acid dye staining ceases. This point or narrow range represents a change in the electrical charges on the nuclear material and the point

of change is conditioned by the relative proportions of nucleic acid and protein which make up the nucleoproteins of the chromatin material. To determine what these proportions of nucleic acid and protein are, the nucleoproteins of the nuclei of the different tissues are obtained as pure chemical individuals and studied by physico-chemical and chemical means. Cataphoretic isoelectric points and acid base titration curves and micro-chemical analyses yield much information about the nucleoproteins which can be correlated with the histochemical staining reactions.

A few of the results of such an investigation reveal that the extracted substances are very similar to the nucleoproteins as they exist in the tissues. The isoelectric ranges of the tissue chromatin and the extracted nucleoproteins are very close to one another so that when the nucleoprotein shows a high nucleic acid to protein ratio the basic staining of the nucleus is much more acid than when the nucleoprotein contains less nucleic acid in relation to its protein content.

Thymus tissue contains very acid nuclei, basic staining occurring as low as pH 3.2 while tumor tissues contain considerably more alkaline nuclei in which comparative basic staining does not occur until pH 4.5. Corresponding differences are shown by the extracted nucleoproteins. The proximal and distal tubules of kidney appear so far to contain the most alkaline nuclei, an interesting observation in view of the deaminizing activity of the kidney.

One of the most interesting observations is that during cell division the chromatin or nucleoprotein changes and becomes much more acid in relation to its condition in the resting nucleus. It is easily possible to stain tumor sections in such a way that mitotic figures are strongly stained while resting nuclei are not stained at all. In view of the correlation between extracted substances and tissue nuclei it is logical to say that during cell division the proportion of nucleic acid to protein in the chromatin has increased. Either new nucleic acid is being formed or protein is being removed from the nucleus during mitosis. With the Tiselius Electrophoresis apparatus, it is hoped and believed that an actual separation of mitotic and resting nuclear material can be made to confirm what already is indicated by the tissue staining reactions.

2. Studies of Allergic Serum Reactions (Dr. Newell).

A study is being made of allergic reactions in humans. Previous work indicates that the allergenic substances, i.e., pollen extracts, danders, house dust, contain small colloidal particles as the active principles. These are too small to function as true antigens in animals but affect the sensitive human.

The first step is to study the nature of the antibody-antigen reaction in humans. If too few antibody molecules react with one antigen particle to cause visible precipitates such as Svedberg found to be the case in the egg white-anti-egg white mixture in the inhibition zone, then one might find evidence of this by more rapid sedimentation in the ultra-centrifuge. Serums from patients sensitive to ragweed pollen were obtained from Dr. W. C. Spain in New York. These were mixed with ragweed and ultracentrifuged at 30,000 revolutions per minute. Top, middle and bottom fractions were separated and sent back for test of their ability to cause passive transfer of sensitivity to the skin of a normal person, and of their action in the skin of ragweed sensitive patients. These tests will determine the antibody and allergen content of the various fractions. Results of these tests are not known at present.

In order to obtain a parallel to these studies in animals, synthetic antigens of various sizes are being prepared. Following the work of Landsteiner and of Haurowitz, arsanilic acid was diazotized and coupled with proteins. Antiserum was produced by injecting these into animals. This reacts with arsanilic acid coupled with simple chemical compounds, but, like the ragweed sensitive serum of humans, it does not precipitate. Such reactions are to be studied in the ultra-centrifuge and then, on the assumption that the artificial compounds are analogous to ragweed pollen extract, a study will be made of methods of using them to cause and cure sensitivity in animals. If such methods are successful, and if the methods are suitable, they will be tried on substances causing human allergy in the hopes of obtaining a more certain curative action from them.

During the past year a study was made of the Shwartzman effect and its application to tumors in rats. A protein-like

material was isolated from coli toxin which was very effective in causing hemorrhage in transplanted rat tumors. It was not thrown down by the ultracentrifuge. A supply of active material was preserved by collecting it on cellophane by filtration under pressure. This was dried and is being saved for further separation by electrodialysis in the Tiselius apparatus.

3. Testing New Chemical Compounds for Their Possible Use in the Treatment of Disease (Mr. Phillips).

This is a new project just now getting under way. The new chemical compounds being synthesized by Dr. Binz and coworkers are to be tested in animals infected with organisms of disease. Dependence on animal tests is necessary, as in vitro tests are, in general, unreliable for such work. It is undecided at present against which diseases tests are to be made, but probably one or more of the following: trypanosomiasis, syphilis and streptococcis infection.

4. Radiation Effects (Dr. Mundell).

Dr. Mundell, in conjunction with the Physics Department, has made studies of the therapeutic effect of X-rays on the blood elements and the organs of mice, and on the transplantable rat carcinoma Walker No. 256, and has determined the lethal dose for mice. A dose of 850 r. units kills mice (20 g.) in 7 days, causes an aplastic anemia in the bone marrow and spleen, a leukopenia and a diapedesis in the lungs and liver, and has also a destructive effect on the mucous membrane of the small intestine.

A Walker carcinoma No. 256 of 12 days is caused to regress completely by 1,350 r. units in 15 days.

The above work has been largely in preparation of standards of comparison to be used in the study of the effect of neutrons to be taken up when the cyclotron is in operation.

Dr. Mundell has been studying also the effect on tumors of fluorescent dyes and inorganic peroxides.

5. The Glover Microörganism (J. O. Ely and Dr. Murray Wright).

Drs. Glover and Engle culture a microörganism with a rather involved life cycle from 100 per cent. of malignant

tissue specimens and from about 95 per cent. of blood samples from human cancer patients. In addition they use these organisms and, after a preliminary period of adaptation to the rat or the guinea pig, produce apparently malignant tumors in 57 per cent. of the rats and in 59 per cent. of the guinea pigs treated.

Our success in culturing the organism from samples of blood from cancer patients has not been good but encouraging. Of the last 75 samples of blood used, 70 per cent. have shown positive cultures of the organism. We feel convinced that it is present in the other samples of blood, but it is extremely difficult to culture.

We are interested in this work because, as it seems to us, the presence of an hitherto undescribed organism associated with malignancy in such a high percentage of cases cannot be ignored in spite of the fact that most cancer specialists feel convinced that bacteria and cancer are not related. Aside from the fact of the possible relationship to the cause of human cancer, the scientific interest in an organism of pleomorphic form is great.

6. Determining the Globulin Rise in Immunized Rabbits, Reticulo-endothelial Blocked Rabbits and Reticulo-endothelial Blocked Rabbits Which Have Been Subsequently Immunized with Egg Albumin (Mr. Smith and Mr. Jennings).

Reports in the literature indicate that on immunization there is a distinct rise in serum globulin. We thought it would be of interest to find if this rise would be inhibited by a reticulo-endothelial blockade, which prevents the formation of antibodies. This experiment is about two-thirds finished. Two weeks or a month should be time enough to do the final analyses, and evaluate the data. The results at the present time mean little until the rest of the analyses are done.

7. Investigation of the Proteinases Produced by Cl. histolyticum (Mr. Smith and Dr. Kocholaty).

Mr. Smith and Dr. Kocholaty are using a rough strain of this organism (the one indistinguishable from *Cl. sporogenes*) and testing its enzyme production on various media, and under various conditions. The presence of proteinase in the media in which the bacteria are grown seems to inhibit the further production of this enzyme. That is, with this

medium enzyme production reaches a certain maximum, and further bacterial growth does not add any enzyme to the solution.

More work will be done in the investigation of the factors that govern enzyme production by this organism under various conditions.

8. Enzymatic Treatment of Bacterial Diseases (Dr. Hoogerheide).

Virulent strains of many pathogenic bacteria produce polysaccharide capsules, which are completely absent in the non-virulent forms. When these virulent bacteria produce an infection, the polysaccharide capsules serve to protect the bacteria against phagocytosis by the leucocytes of the body. In addition, the polysaccharides are often produced in such large amounts that they find their way into the blood stream, where they neutralize any antibodies that might act on the bacteria. Consequently, these bacterial polysaccharides not only render bacteria more pathogenic, but also often make antiserum therapy ineffective.

This problem is the preparation of an enzyme solution which will readily hydrolyze these polysaccharides. In the case of certain bacterial diseases, such an enzyme should remove the polysaccharides from the circulating blood, and thus make treatment with antisera effective. If the enzyme were present in sufficient concentration, it should even dissolve the capsules from the bacteria themselves, and render them susceptible to phagocytosis.

The little work that has been done in this field indicates that such an investigation is certainly worthwhile. Dubos found that mice could be saved from an otherwise lethal dose of Pneumococcus Type III by the injection of an enzyme which hydrolyzed the capsular polysaccharide of this organism.

The animal body does not contain any enzymes which hydrolyze these polysaccharides, so it is necessary to obtain this from other sources. We have worked with polysaccharides obtained from Pneumococcus Types I, II, III, and with Friedlander's bacillus. The polysaccharides specific for each type were isolated, added to a suitable culture medium, and inoculated with a small amount of soil or sewage. Cer-

tain innocuous bacteria in the soil or sewage samples attacked the polysaccharide and caused it to disappear from the culture medium. We have been able to isolate, in pure culture, several strains of bacteria which are able to destroy these polysaccharides. These will be used to prepare enzyme solutions.

The polysaccharides produced by various pathogenic microörganisms are chemically dissimilar, and consequently, an enzyme which attacks the polysaccharide of Pneumococcus Type I may not attack that of Type II or Type III. It is possible, however, that a bacterium might be found which would be able to produce an enzyme which would hydrolyze polysaccharides from a number of pathogenic bacteria. In this case, the enzyme solution could be used for treatment of the various types of pneumonia, and perhaps for certain other diseases as well.

Although this work has dealt only with those organisms producing pneumonia, it may later be extended to other pathogenic organisms, such as those producing anthrax, colitis, black-leg, dysentery, etc.

THE MICROCHEMICAL DEPARTMENT.

DOCTORS H. K. ALBER, J. HARAND AND MR. WM. G. BATT.

1. Construction.

During the first part of the year, the laboratory was constructed according to original plans, and equipped with the best materials and apparatus available. All of the data pertaining to this construction were collected and incorporated in an article which will appear in the December 1937 issue of the JOURNAL OF THE FRANKLIN INSTITUTE. By the middle of January 1936 the laboratory was considered finished in so far as the general set-up was concerned, although numerous improvements and new methods have been incorporated as time permitted or the incoming requests demanded.

2. Aims and Purposes.

(*a*) The microchemical department performs all the analytical work on new synthetic compounds or isolated products from research work of the different laboratory groups. If the analytical work is connected directly with the problem,

however, it should remain in the experienced hands of the research worker himself. The advantages of the microchemical method are shown not only by its adaptability to analysis of small amounts of material, which may be available, but also as a time-saving factor. The successive steps in purification, completeness of certain reactions, etc., can be tested by micro methods in a more efficient way than by ordinary procedures.

(*b*) It has been found that some cases of requests for analytical work have stimulated a search for better or newer methods, and some research has been done along this line. The factor of time-saving and economic distribution of work has always been carefully considered. Many improvements have been developed as this year has progressed and a closer insight was gained in the behavior of biological substances under investigation; e.g., numerous complete analyses on nucleo proteins, nucleic acids, histones, etc., submitted by Dr. Kelley, have been disturbed by the exceptional hygroscopicity of the dried samples. In order to offset this influence, new drying methods with the complete exclusion of moist air have been developed, and research in this direction may be considered finished with the setting-up of a very efficient drying apparatus. Later, from experience gained in numerous determinations, a simpler, yet equally efficient procedure was developed. The samples are taken for analysis with the minimum of exposure to air, and weighed as moist samples. A very accurate moisture determination is performed on each sample, and the ultimate results calculated upon the dry basis.

(*c*) The microchemical group has functioned in the role of advisory group in certain problems connected with analytical work, and with the search for applications of some of the analyzed compounds.

(*d*) The fundamental postulate of the Foundation, to contribute original research work, was included in the program. Unfortunately, only very little has been done in this direction, since the analytical work occupied nearly the whole time of the group. It was hoped that the addition of a new member to the microchemical group, Mr. William G. Batt, in September would relieve this situation, but the synthesic

work has also increased. In spite of the additional analyst the original group has less time for research than before.

3. Activities.

(*a*) *Analytical Work:* 99 reports as to method have been given out in answer to 93 requests from the various members of the Foundation. Six special reports deal with contributions in regard to improving analytical procedures, e.g., determinations of silver, barium, and phosphorus in organic substances in one weighed sample, analysis of methionine by a semi-micro and a micro-procedure; comparison of results of nitrogen determinations by the Dumas and Kjeldahl procedure with special reference to certain types of difficulty combustible materials (Kelley's samples of histones, etc.); experience with the determination of ethoxyl and methoxyl groups in organic compounds; report on the construction of the microchemical laboratory, and a preliminary report on the semi-quantitative estimation of sulfur in organic compounds.

The attached table shows the number of analyses performed during the period mentioned. Numerous analyses necessary for standardization of the different apparatus at the time of their assembly have been omitted. A few of the interesting problems which we were able to solve may be mentioned here: From enzyme preparations, crystals separated out on storage, which seemed to contain some activity. The assumed "organic compounds" were definitely identified in a very short time as sodium chloride in the one case and as magnesium ammonium hexahydrate in the other case. The active principle in Dr. Neale's work has been identified by very accurate microchemical determinations as xanthine. The nucleo-proteins, nucleic acids, thymus histones of Dr. Kelley's work offered very interesting aspects for the microanalyst, since the substances contained considerable amounts of ash; five elements (C, H, N, S, P) and the constituents of the ash as well as the moisture content of the exceptionally hygroscopic substances had to be determined in each of the products. The manometer liquids (Clerici solution) in Dr. Elliott's work had changed, and accurate specific gravity determinations were necessary to introduce corrections for the manometric values obtained over a longer period. Since the

NUMBER OF ANALYSES JAN 31 to DEC. 1, 1937.

	Standard Samples Blank Tests	Research
Qualitative Analysis:		
Elements (C, H, N, S, P, Halogen, B, NH_3, metals such as Na, K, Ca,), ash and ignition tests	87	434
Melting point (hot stage and capillary method)	46	129
Specific gravity	15	16
Refractive index	3	11
Boiling point	2	9
pH	1	3
Microscopic investigations	1	3
Microchemical procedures (recrystallization, distillation, sublimation, extraction)	50	51
Total qualitative tests	205	656
Quantitative Analysis:		
C-H (of each)	72	226
N-Dumas	78	138
N-Kjeldahl	16	—
Halogen (Cl, Br, I)	30	20
S	10	73
P	14	74
As	14	—
Ba in presence of P and Ag	9	8
Ag in presence of Ba and P	3	6
Ba alone	2	25
Fe (in cytochrome)	26	5
Methoxyl-groups	3	3
COOH-groups	17	3
SiO_2	—	1
Titrations	51	4
Cholesterol	1	2
Ash, residues	6	77
Moisture	7	49
Molecular weights	24	1
Electrolysis	3	—
Total quantitative tests	386	715
Total determinations	591	1371

Sum total 1962

amounts of these liquids, after removal from the manometers, were so small the ordinary methods could not be used; but the micro-procedure of Alber (as yet unpublished) was applied and considered an asset. The melting point behavior of different compounds on the hot stage in comparison with the ordinary capillary methods has been successfully introduced as a new means of identification of organic compounds.

(*b*) *Research Problems:* As mentioned before, the main interest of the group is directed towards reducing time-consuming operations, either in order to have more time available for research work or to speed up the work itself, e.g., as in the sulfur determination, which at the present requires 3 to 4 hours. One of the steps in this direction is, e.g., the development of so-called semi-quantitative estimations of the elements in organic compounds, with an accuracy of about 5 per cent. and maximum time consumption of 30 minutes. In this way, sulfur estimations carried out previously to the actual quantitative determination indicate the appropriate amount of sample to be taken, and help to prevent an inaccurate determination, which may result from taking an improper amount of sample. This inaccuracy would not be noticed until the end of the determination. Notably in the cases of biological products, where sometimes ash constituents up to 50 per cent. and more have been found, such a preliminary test is of prime importance. Much experience has been gained on the estimation of sulfur, halogens, and phosphorus; at present experiments are being conducted on nitrogen in various combinations. This type of work has been considered by chemists as an improvement over the previous procedures, and has the endorsement of men well known in the organic field. General experiments are being performed to fit a qualitative scheme with micro-procedures for organic compounds, a problem on which Alber had already worked before his connection with the Foundation. Included in this scheme are methods on specific gravity, melting points on the hot stage, recrystallizations, preparations of derivatives on a micro scale, and extraction procedures.

A procedure for drying very hygroscopic substances in closed weighing tubes, using simple arrangements, has been developed.

A method has been developed to determine silver, barium, and phosphorus in one weighed sample. The work on this problem has been carried out by J. Harand.

Problems under consideration at the present time are as follows:

Reducing the time of the sulfur determination through the application of a new type of combustion tube.

The determination of Bi and Se, by use of the Elek-Hill-Parr bomb method.

The determination of fluorine in organic compounds.

A micro method for quantitative determination of cholesterol in blood, using the Linderstrøm-Lang technique. Special emphasis will be given to the work in closed capillaries, and complete precipitation. The determinations are to be carried out on a single drop of blood from rats (0.01 ml.), in order to follow certain changes in the free and esterified cholesterol content with progressive tumor growth, pregnancy, castration, etc.

Rational Psychromatics.—E. V. HILL. (*Heating, Piping, and Air Conditioning*, Vol. 9, No. 10.) The air conditioning industry will be one of the great industries of mankind. With this in mind it may be in order to simplify and organize engineering practices dealing with it. The psychrometer is one of the basic instruments used in air conditioning. Both thermometers of this instrument have similar scales. The original scale proposed by Fahrenheit was much different than that used on the thermometer today. If we take the present graduations (Fahrenheit) and multiply them by 0.241, the specific heat of air, the result will be practically Fahrenheit's original scale, and it then becomes logical and useful, for each degree on the scale will represent the sensible heat in one pound of air. In the case of the wet bulb thermometer the scale could be changed so that it will read not in degrees dry bulb, but in degrees of total heat. By placing these two thermometers in a frame, a whirling psychrometer is constructed. When a reading is taken in air with the sensible and total heat scales, an example of such reading would be 15 on the dry bulb and 23 on the wet bulb. This means, of course that the air contains 15 B.t.u. per lb. of sensible heat and 23 B.t.u. of total heat. By subtracting 15 from 23 we obtain 8, which is the latent heat of the air. A dewpoint scale would be graduated from zero upward in B.t.u. degrees of latent heat. Zero would be absolutely dry air. Any point on a psychrometric chart using these new scales will read correctly with regard to temperatures, wet bulb, dry bulb, and dew point, but what is far more important, it gives immediately the thermal values, which after all are the important determinations in air conditioning work.

R. H. O.

SPIRAL SPRINGS WITH A SMALL NUMBER OF TURNS.

BY

R. P. KROON and C. C. DAVENPORT,

Experimental Division, Westinghouse Electric and Manufacturing Company.

INTRODUCTION.

Spiral springs with a large number of turns have been widely used in various fields during several centuries. Their theory was explored by Castigliano [1] and Föppl.[2] Lately an original and very interesting paper about this subject was presented by Van den Broek,[3] who showed that some of the older work was erroneous in several respects. In spite of these discrepancies it can be said that the problem of spiral springs with a large number of turns is solved.

A large number of turns is desirable where small forces are combined with large motions (small spring constant). Practical considerations, however, sometimes require a spring of such a stiffness as can only be obtained by using a comparatively thick cross section and few turns. The problem is then to find the best design for given limitations (flexibility, space, maximum motion, maximum stress). To accomplish this it seemed unavoidable to work out a theory for spiral springs with few turns. This theory is presented here.

We have limited ourselves to the case where one extremity of the coil is rigidly fixed, while the other extremity moves in a circle concentric with the geometric center of the spiral. During this motion, the angle between this end of the spiral and the circle shall stay the same. For example, the inner end of the spring may be rigidly attached to a shaft, while the outer end is clamped to a rim moving in a circle concentric with the shaft.

It can easily be shown that with such conditions and for a large number of turns, the spring will be in pure bending, so that the bending moment at any point is the same.

---

[1] Castigliano, "Theorie der Biegungs- und Torsions Federn," 1888.

[2] Föppl, A., "Vorlesungen über die technische Mechanik," Vol. 3, 10th edition, 1927, p. 235.

[3] Van den Broek, "Spiral Springs," *Trans. A. S. M. E.*, 1931, A.P.M.–53–18.

The picture changes entirely for a limited number of turns. There the spring is no longer subject to pure bending. At each end of the spiral we have generally, besides a moment, a force having a radial and a tangential component. Therefore the bending moment along the spiral varies (see for example, curve shown in Fig. 17) and comparing the maximum stress with the average, we may speak of "stress concentration due to limited number of turns." It was expected that

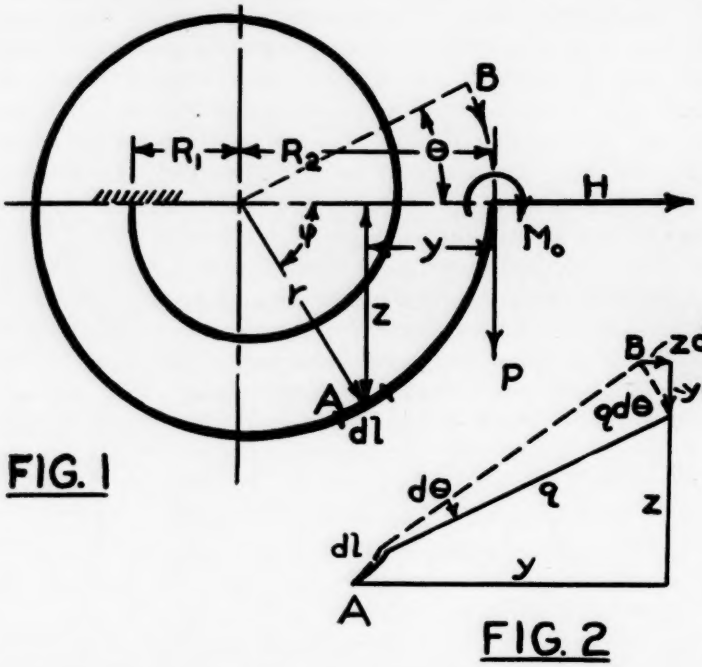


FIG. 1

FIG. 2

this stress concentration would decrease in some way with an increasing number of turns. Our analysis reveals that instead of decreasing gradually, the stress concentration curve, when plotted against the number of turns (Fig. 3) shows decided maxima and minima, the minima appearing approximately where the number of turns is an integer.

The uneven distribution of the bending in the coil also affects the flexibility, which is less than what would correspond to that of a spring with a very large number of turns (Fig. 4).

FIG. 3.

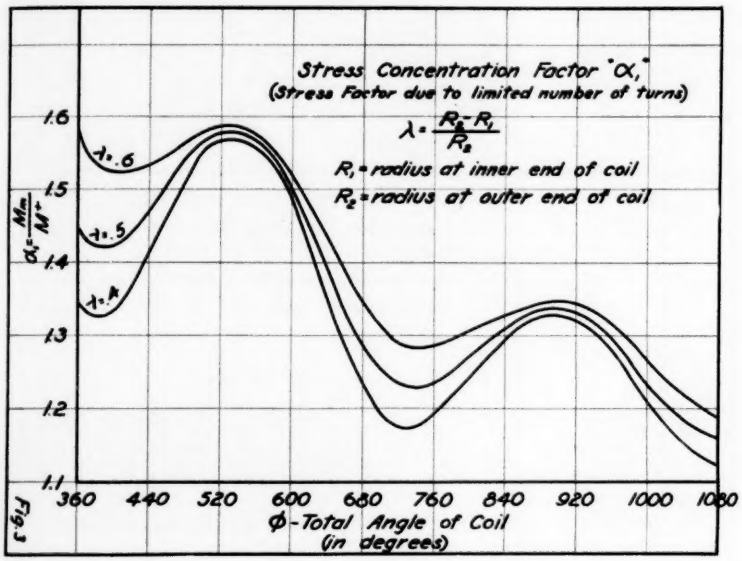
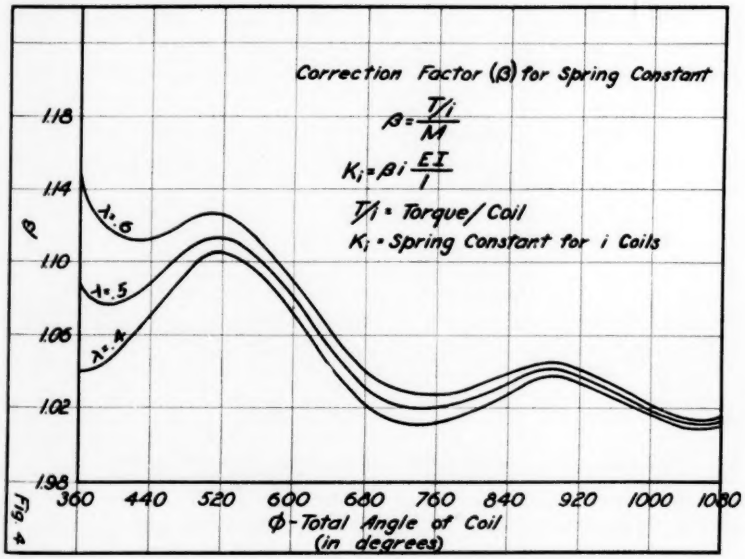
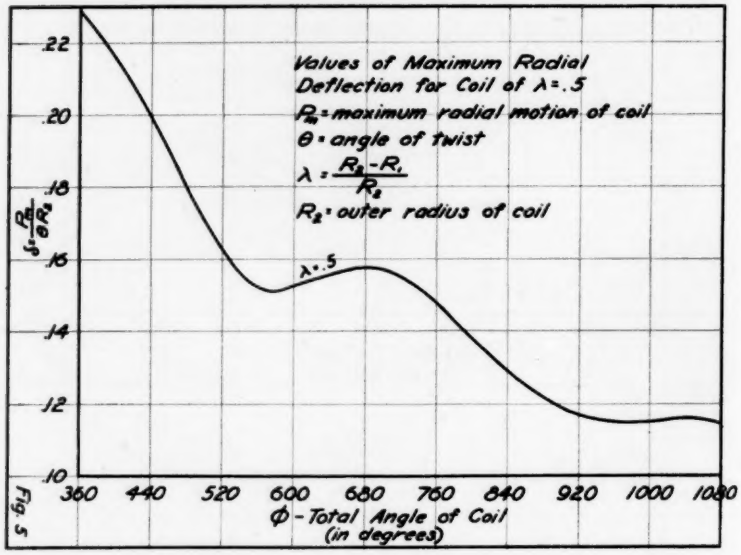

Stress Concentration Factor "α,"
(Stress Factor due to limited number of turns)
$\lambda = \frac{R_2 - R_1}{R_2}$
R_1 = radius at inner end of coil
R_2 = radius at outer end of coil
$\alpha = \frac{M_{max}}{M}$
λ=.6
λ=.5
λ=.4
1.6
1.5
1.4
1.3
1.2
1.1
360 440 520 600 680 760 840 920 1000 1080
Φ-Total Angle of Coil
(in degrees)
Fig 3

FIG. 4.


Correction Factor (β) for Spring Constant
$\beta = \frac{T/1}{M}$
$K_i = \beta i \frac{EI}{l}$
T/1 = Torque/Coil
K_i = Spring Constant for i Coils
β
λ=.6
λ=.5
λ=.4
1.18
1.14
1.10
1.06
1.02
.98
360 440 520 600 680 760 840 920 1000 1080
Φ-Total Angle of Coil
(in degrees)
Fig 4

During deflection, the windings tend to approach each other at certain points and a knowledge of the radial motion along the spiral is valuable to determine the permissible gap between adjacent windings (Figs. 5 and 6).

FIG. 5.



A practical example is shown to illustrate the use of the theory such as to obtain the best design for given limitations.

ANALYSIS.

The spring is considered fixed at the inner end and we will represent the reaction of the rim at the outer end by the moment M_0 and the forces P and H (Fig. 1). At any point A along the coil the bending moment will be

$$M = M_0 + Py + Hz. \qquad (1)$$

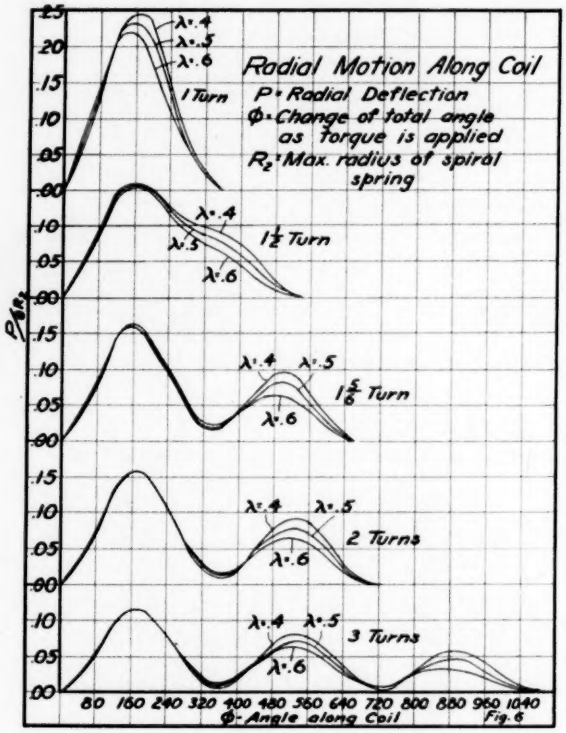
Three equations are needed to determine M_0, P and H. They are established by considering the deflection of the coil. Considering bending only a small element dl at A will undergo a distortion such that the relative angular motion between the

ends of the element is equal to

$$d\theta = \frac{Mdl}{EI}.$$

Integrating over the whole length of the coil, the total angle

FIG. 6.



of twist becomes

$$\theta = \int_{\varphi=0}^{\varphi=\phi} \frac{(M_0 + Py + Hz)dl}{EI}, \qquad (2)$$

φ being the angle between the radii at A and B, and ϕ the total angle of the spiral.

We have assumed our boundary conditions to be such that the outer end B moves along a circle. Due to bending

of the element dl, point B will move over a distance $q d\theta$ (Fig. 2). From similar triangles it can be seen that $y d\theta$ is the tangential component, while $z d\theta$ is the radial component of $q d\theta$. Integrating over the whole spiral, the tangential and radial displacements of the end B are found, which, on the other hand, must be equal to $R_2\theta$ and zero respectively.

$$R_2\theta = \int_{\varphi=0}^{\varphi=\phi} y d\theta = \int_{\varphi=0}^{\varphi=\phi} \frac{yMdl}{EI}$$

$$= \int_{\varphi=0}^{\varphi=\phi} \frac{(M_0 y + Py^2 + Hyz)dl}{EI}. \quad (3)$$

$$0 = \int_{\varphi=0}^{\varphi=\phi} z d\theta = \int_{\varphi=0}^{\varphi=\phi} \frac{zMdl}{EI}$$

$$= \int_{\varphi=0}^{\varphi=\phi} \frac{(M_0 z + Pyz + Hz^2)dl}{EI}. \quad (4)$$

We introduce $PR_2 = M_1$ and $HR_2 = M_2$ and get:

$$M_0 \int \frac{dl}{R_2} + M_1 \int \frac{ydl}{R_2^2} + M_2 \int \frac{zdl}{R_2^2} = \frac{\theta EI}{R_2}, \quad (2')$$

$$M_0 \int \frac{ydl}{R_2^2} + M_1 \int \frac{y^2 dl}{R_2^3} + M_2 \int \frac{yzdl}{R_2^3} = \frac{\theta EI}{R_2}, \quad (3')$$

$$M_0 \int \frac{zdl}{R_2^2} + M_1 \int \frac{yzdl}{R_2^3} + M_2 \int \frac{z^2 dl}{R_2^3} = 0. \quad (4')$$

Apparently for the solution of these three equations we need the following six integrals:

$$a = \int_{\varphi=0}^{\varphi=\phi} \frac{dl}{R_2}, \qquad b = \int_{\varphi=0}^{\varphi=\phi} \frac{ydl}{R_2^2}, \qquad c = \int_{\varphi=0}^{\varphi=\phi} \frac{zdl}{R_2^2},$$

$$d = \int_{\varphi=0}^{\varphi=\phi} \frac{y^2 dl}{R_2^3}, \qquad e = \int_{\varphi=0}^{\varphi=\phi} \frac{z^2 dl}{R_2^3}, \qquad f = \int_{\varphi=0}^{\varphi=\phi} \frac{yzdl}{R_2^3}.$$

The evaluation of these integrals is carried out in Appendix A and the results shown in Figs. 7–12. All six expressions are dimensionless.

FIG. 7.

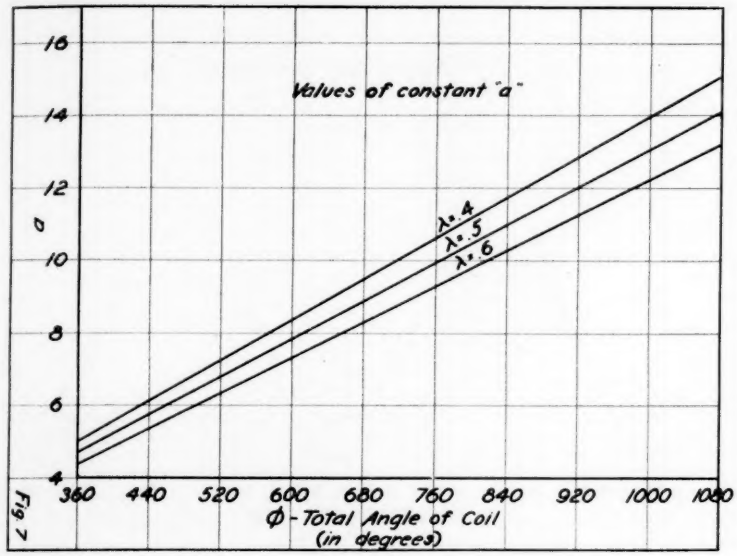

Values of constant "a"
λ=.4
λ=.5
λ=.6
a
16
14
12
10
8
6
4
360
440
520
600
680
760
840
920
1000
1080
Φ - Total Angle of Coil
(in degrees)
Fig. 7

FIG. 8.

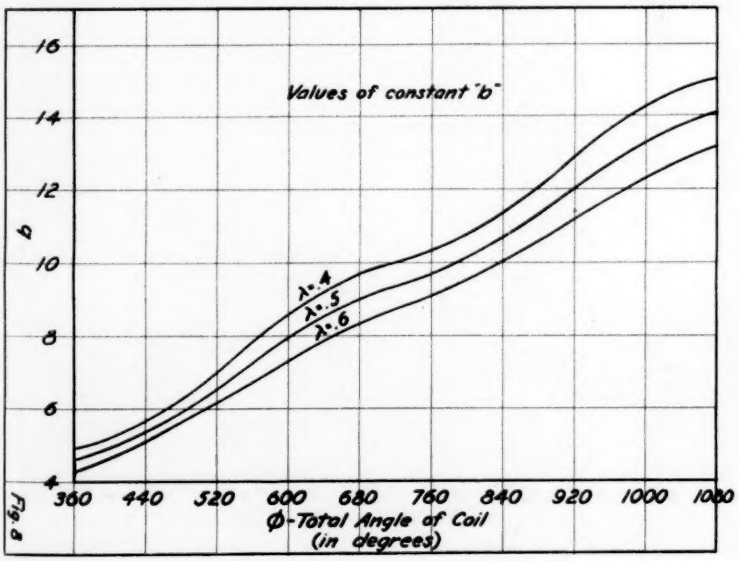

Values of constant "b"
λ=.4
λ=.5
λ=.6
b
16
14
12
10
8
6
4
360
440
520
600
680
760
840
920
1000
1080
Φ - Total Angle of Coil
(in degrees)
Fig. 8

FIG. 9.

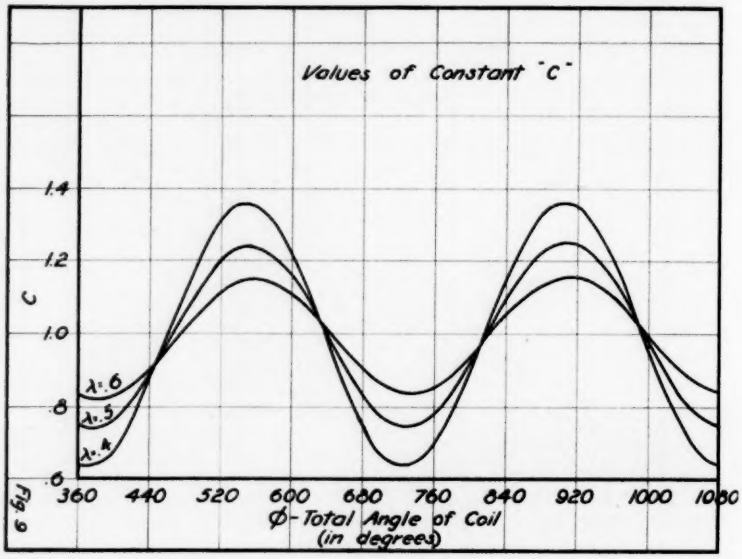

Values of Constant "C"
1.4
1.2
1.0
.8
.6
C
λ=.6
λ=.5
λ=.4
360 440 520 600 680 760 840 920 1000 1080
Φ-Total Angle of Coil
(in degrees)
Fig 9

FIG. 10.

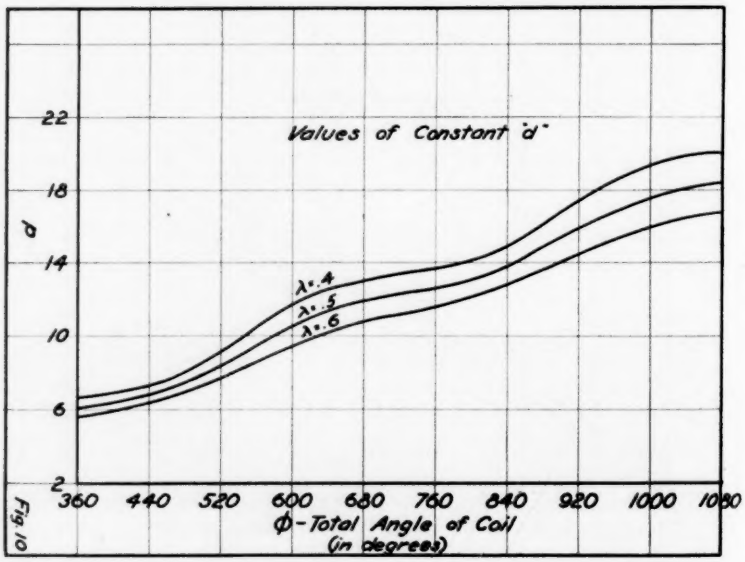

Values of Constant "d"
22
18
14
10
6
2
d
λ=.4
λ=.5
λ=.6
360 440 520 600 680 760 840 920 1000 1080
Φ-Total Angle of Coil
(in degrees)
Fig 10

FIG. 11.

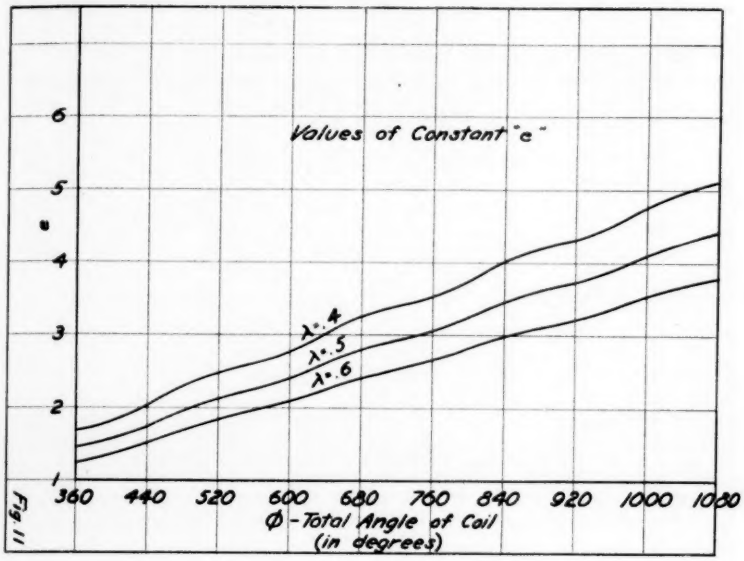
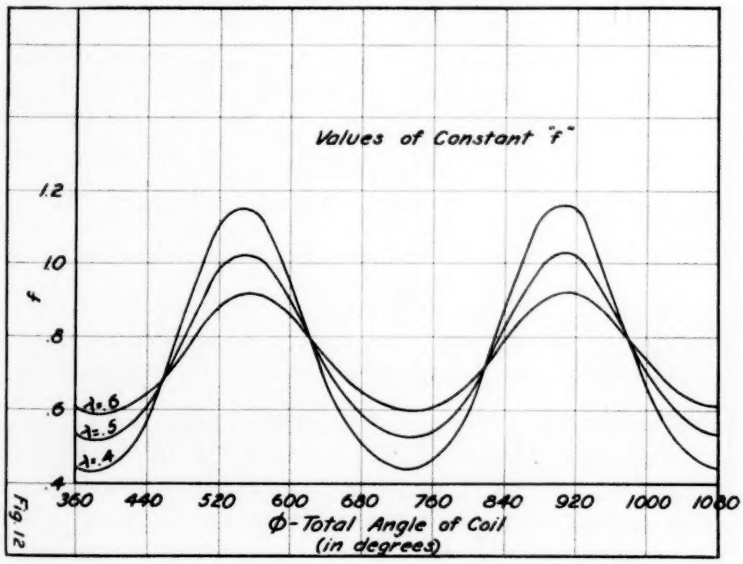

Values of Constant "e"
e
6
5
4
3
2
1
λ=.4
λ=.5
λ=.6
360 440 520 600 680 760 840 920 1000 1080
Φ - Total Angle of Coil
(in degrees)
Fig 11

FIG. 12.


Values of Constant "f"
f
1.2
1.0
.8
.6
.4
λ=.6
λ=.5
λ=.4
360 440 520 600 680 760 840 920 1000 1080
Φ - Total Angle of Coil
(in degrees)
Fig 12

Calling $M^* = \frac{\theta EI}{l} = \frac{\theta EI}{aR_2}$ the "nominal" bending moment, as it corresponds to the moment in a spring with a very large number of turns with the same boundary conditions, equations 2′, 3′ and 4′ reduce to

$$aM_0 + bM_1 + cM_2 = aM^*, \tag{2''}$$

$$bM_0 + dM_1 + fM_2 = aM^*, \tag{3''}$$

$$cM_0 + fM_1 + eM_2 = 0, \tag{4''}$$

the solution being

$$\frac{M_0}{M^*} = \frac{f^2 + be - cf - de}{\frac{b^2e}{a} + \frac{c^2d}{a} + f^2 - \frac{2bcf}{a} - de}, \tag{5}$$

$$\frac{M_1}{M^*} = \frac{c^2 + be - cf - ae}{\frac{b^2e}{a} + \frac{c^2d}{a} + f^2 - \frac{2bcf}{a} - de} \tag{6}$$

$$\frac{M_2}{M^*} = \frac{af + cd - bc - bf}{\frac{b^2e}{a} + \frac{c^2d}{a} + f^2 - \frac{2bcf}{a} - de}. \tag{7}$$

Since the constants a, b, c, d, e and f depend only on the number of turns (total angle ϕ) and the ratio of inner and outer diameter (R_1/R_2) the values M_0/M^*, M_1/M^*, M_2/M^* can conveniently be plotted as functions of ϕ; the dimensionless quantity $\lambda = \frac{R_2 - R_1}{R_2}$ being used as parameter (Fig. 13).

The bending moment at any point of the coil is equal to $M = M_0 + \frac{M_1}{R_2}y + \frac{M_2}{R_2}z$. Of particular interest is the maximum moment M_m in the coil, for which $\frac{dM}{d\varphi} = 0$ (Appendix C).

The ratio M_m/M^* may be called the "Stress concentration" (α_1) caused by the limited number of turns (Fig. 3). It is this ratio which is important for all stress calculations.

The radius R_m at which the maximum bending stress occurs is shown in Fig. 14. The corresponding angle, φ_m, is given in Fig. 16.

FIG. 13.

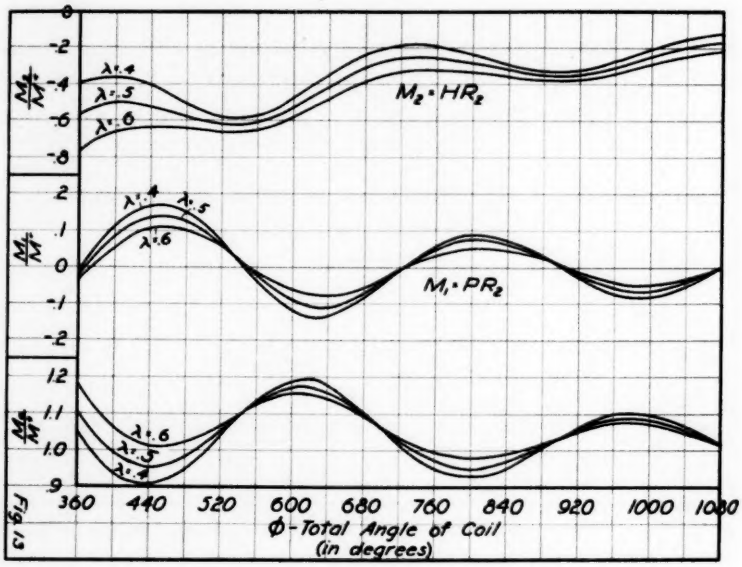

$M_2 = HR_2$
$M_1 = PR_2$
λ=.4
λ=.5
λ=.6
$\frac{M_2}{M}$
$\frac{M_1}{M}$
$\frac{M_3}{M}$
0
-2
-4
-6
-8
2
.1
0
-1
-2
1.2
1.1
1.0
.9
360
440
520
600
680
760
840
920
1000
1080
Φ - Total Angle of Coil
(in degrees)
Fig. 13

FIG. 14.

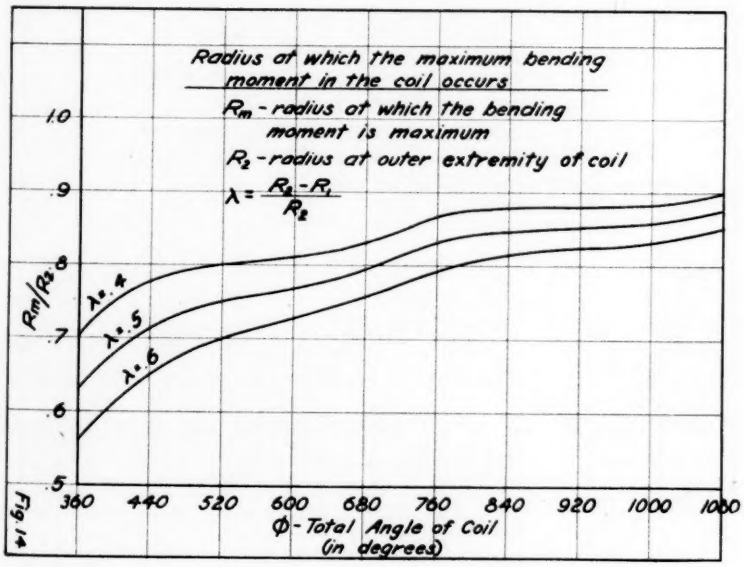

Radius of which the maximum bending moment in the coil occurs
R_m - radius of which the bending moment is maximum
R_2 - radius at outer extremity of coil
$\lambda = \frac{R_2 - R_1}{R_2}$
R_m/R_2
1.0
.9
.8
.7
.6
.5
λ=.4
λ=.5
λ=.6
360
440
520
600
680
760
840
920
1000
1080
Φ - Total Angle of Coil
(in degrees)
Fig. 14

FIG. 15.

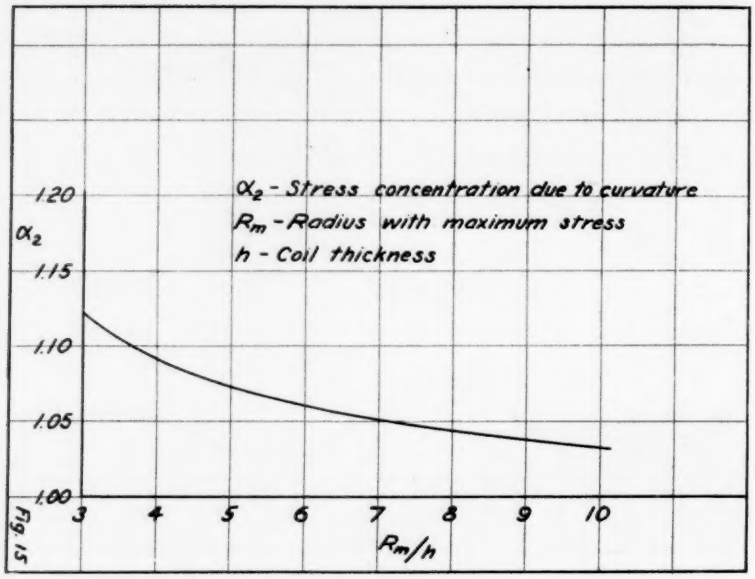
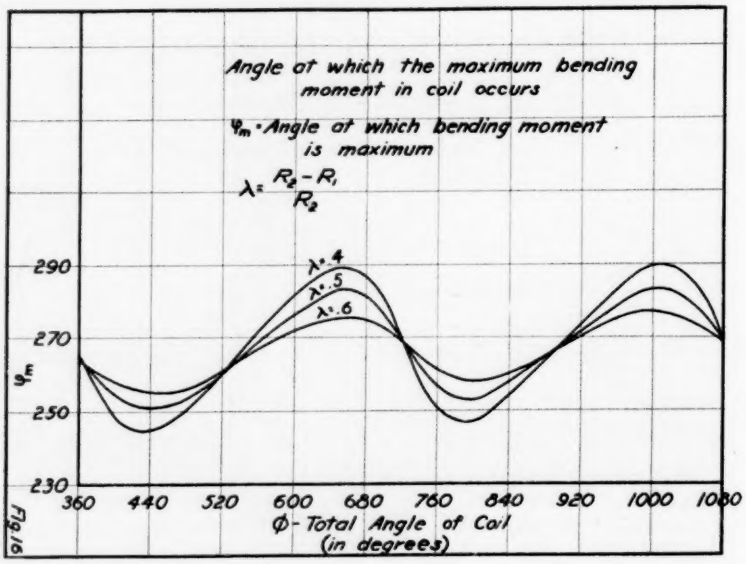

α_2 - Stress concentration due to curvature
R_m - Radius with maximum stress
h - Coil thickness
α_2
1.20
1.15
1.10
1.05
1.00
3
4
5
6
7
8
9
10
R_m/h
Fig 15

FIG. 16.


Angle at which the maximum bending moment in coil occurs
ψ_m - Angle at which bending moment is maximum
$\lambda = \frac{R_2 - R_1}{R_2}$
λ=.4
λ=.5
λ=.6
ψ_m
290
270
250
230
360
440
520
600
680
760
840
920
1000
1080
ϕ - Total Angle of Coil (in degrees)
Fig 16

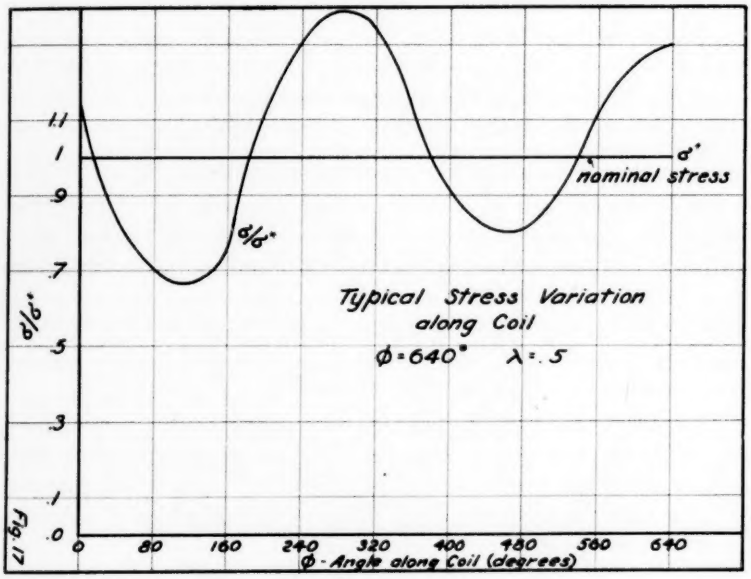
(b) Stress Concentration Due to Non-linear Stress Distribution in Curved Beam.

The "curved beam effect" on the stress is usually of minor importance. It depends only on the ratio between the radius of curvature and the thickness of the coil.[4] This stress concentration α_2 can be taken directly from the curve in Fig. 15.

The final stress concentration is

$$\alpha = \alpha_1 \alpha_2. \tag{8}$$

FIG. 17.



(c) Flexibility—Spring Constant.

The spring constant K of a spiral spring for angular motion is the torque which produces a unit angular deflection (1 radian). Since the torque $M_0 + PR_2 = M_0 + M_1$ produces an angle θ (Fig. 1), the spring constant is $\frac{M_0 + M_1}{\theta} = K$. We will again compare a spiral with a limited number of turns with one having a very large number of turns, for which we have the spring constant $\frac{M^*}{\theta} = K^*$. For this purpose we

[4] See Timoshenko, "Strength of Materials," Part II, p. 427.

may introduce a "correction factor" β defined by $K = \beta K^*$, K^* being

$$\frac{EI}{l} = \frac{EI}{aR_2} \tag{9}$$

Then

$$\beta = \frac{M_0 + M_1}{M^*}.$$ Values of β are given in Fig. 4.

It is remarkable that even for considerable angular motion, the load-deflection curve is practically a straight line. This fact has been mentioned by Van der Broek [5] and was also verified by our own model tests. The obvious explanation is that the flexibility of the spring is little affected by a change in the shape of the spiral, as long as the length stays the same.

(d) Radial Motion Along Winding—Permissible Gap.

For efficient use of material and space it is usually desirable to decrease the gap between adjacent turns to a minimum. During deflection the coils tend to approach each other in certain points. As soon as there is metal to metal contact the spring becomes much stiffer (sudden nick in load deflection curve) and there results an extra stress concentration at the point of contact.

Consider the spring fixed at its outer end. The radial motion along the spiral can then be found as follows: As a portion dl of the spring (Fig. 18) deflects (angle of deflection $d\theta$), any point o moves to o'. The radial motion of o due to the deflection of dl is

$$dp = qd\theta \sin \gamma.$$

Also, from the law of sines

$$\frac{r}{q} = \frac{\sin \gamma}{\sin (\varphi - \chi)}.$$

Therefore, substituting

$$d\theta = \frac{Mdl}{EI},$$

$$dp = \frac{Mdl}{EI} r \sin (\varphi - \chi).$$

[5] Loc. cit.

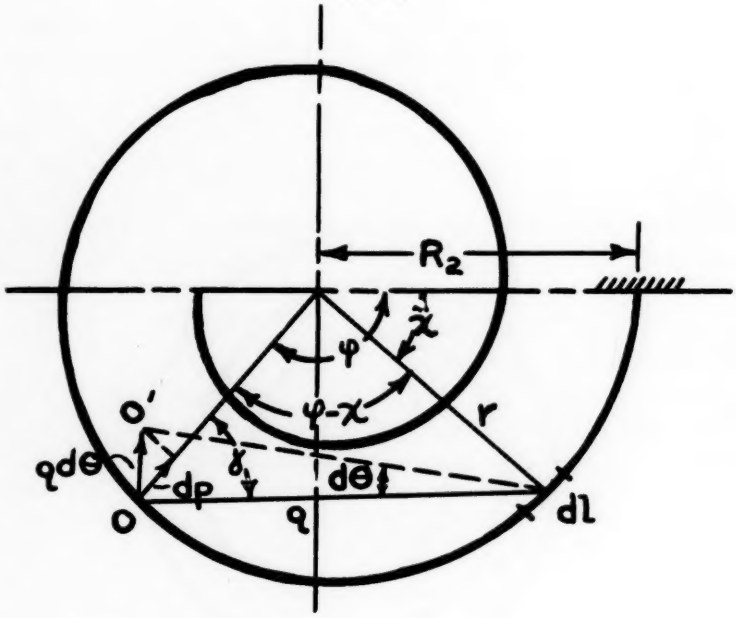
Integrating from $\chi = 0$ to $\chi = \varphi$, we obtain the total radial motion at point o:

$$p = \int_{\chi=0}^{\chi=\varphi} \frac{Mdl}{EI} r \sin(\varphi - \chi). \tag{10}$$

We rewrite this

$$\frac{EIp}{R_2^2} = \int_{\chi=0}^{\chi=\varphi} \frac{(M_0 + Py + Hz) r \sin(\varphi - \chi) dl}{R_2^2}$$
$$= SM_0 + TM_1 + UM_2, \tag{11}$$

FIG. 18.



where S, T and U are defined as

$$S = \int_{\chi=0}^{\chi=\varphi} \frac{r \sin(\varphi - \chi) dl}{R_2^2},$$

$$T = \int_{\chi=0}^{\chi=\varphi} \frac{ry \sin(\varphi - \chi) dl}{R_2^3},$$

$$U = \int_{\chi=0}^{\chi=\varphi} \frac{rz \sin(\varphi - \chi) dl}{R_2^3}.$$

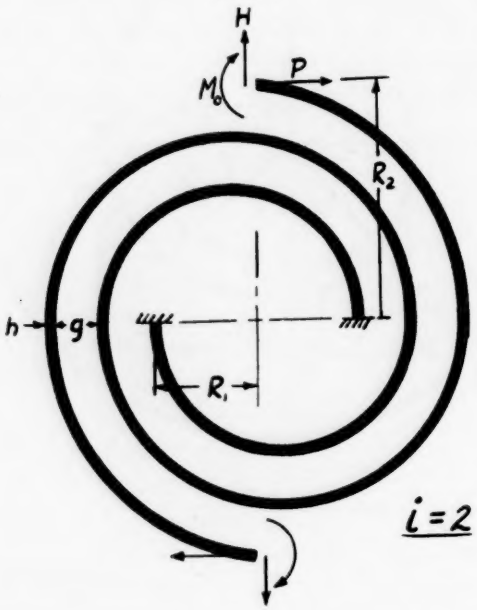
These integrals are evaluated in Appendix D. Some deflection curves are shown in Fig. 6. The value plotted on the sheet is dimensionless and equal to $\frac{p}{\theta R_2}$. Since the maximum radial deflection p_m always occurs approximately at $\varphi = 180°$, it is possible to obtain this value without solving for p along the whole length of the spiral (Fig. 5).

To determine the permissible gap it is necessary to consider the relative motion of adjacent coils.

SPRINGS MADE UP OF SEVERAL SPIRALS.

Where i spiral springs (all in one plane) are acting in parallel, the total spring constant is i times that of the single spring: $K_i = iK$ (see Fig. A).

FIG. A



The amount of gap for such a construction can be found from

$$g + h = \frac{R_2 - R_1}{ni}, \tag{13}$$

n being the number of turns.

The nominal stress becomes

$$\sigma^* = \frac{6M^*}{wh^2} = \frac{6\theta Ewh^3}{12aR_2wh^2} = \frac{\theta Eh}{2aR_2}. \qquad (14)$$

The stress concentration α_1 can be taken from Fig. 3.

NUMERICAL EXAMPLE.

Suppose that for a spring of rectangular cross-section the following characteristics are required:
$R_2 = 5''$, $R_1 = 3''$, width $w = 3/4''$, 2 spirals per spring.

Torque 600 in. lbs., spring constant approximately $K_i = 2400.$ in/rad. corresponding to an angular motion of approximately $\theta = .25$ radians $= 14.3°$.

We see that $\lambda = \frac{5-3}{5} = .4.$ Applying equation (9), we find for the total spring constant

$$K_i = i\beta\frac{IE}{aR_2} = i\beta\frac{Ewh^3}{12aR_2}, \text{ so that } h^3 = \frac{12aR_2K_i}{I\beta Ew}.$$

We will now arbitrarily make our gap g so that under full torque there is still $1/5\ g$ left between windings. The maximum radial motion is always at approximately 180° from the outer end, and the maximum relative motion will never be larger than this absolute motion. We can, therefore, put for two coils:

$$g = 6/5p_m = 6/5\delta\theta R_2 \quad \text{(Fig. 5)}.$$

At the same time the gap is geometrically determined by (13):

$$g + h = \frac{R_2 - R_1}{ni} = \frac{\lambda R_2}{ni}.$$

Then, combining the above equations, we obtain

$$6/5\delta\theta R_2 + \sqrt[3]{\frac{12aR_2K_i}{i\beta Ew}} - \frac{\lambda R_2}{ni} = 0.$$

In which expression we introduce the numerical values of our example with $E = 30 \times 10^6$ for steel.

$$1.5\delta + \sqrt[3]{3.2 \times 10^{-3}\frac{a}{\beta}} - \frac{1}{n} = 0 = \text{say } y.$$

To find the number of turns n, we will make some trials, y being 0 for the correct value. The values for δ are taken from Fig. 5 as if λ were .5 instead of .4, since Fig. 6 shows that the maximum radial deflections do not vary much with λ for $\varphi > 540°$. The values of a and β are to be found in Fig. 7 and Fig. 4 respectively.

$\phi = 600$, $\quad \delta = .1525$, $\quad a = 8.38$, $\quad \beta = 1.072$,
$y = .2388 + \sqrt[3]{.0250} - .600 = -.0687$,

$\phi = 660$, $\quad \delta = .157$, $\quad a = 9.22$, $\quad \beta = 1.032$,
$y = .2355 + \sqrt[3]{.0286} - .545 = -.0035$,

$\phi = 720$, $\quad \delta = .1552$, $\quad a = 10.06$, $\quad \beta = 1.012$,
$y = .2328 + \sqrt[3]{.0318} - .500 = +.0495$.

It is seen that the true value for ϕ is about 664° or 1.84 turns per coil. Then

$$g + h = \frac{R_2 - R_1}{hi} = \frac{2}{1.84 \times 2} = .543'' = \text{say}\frac{35''}{64},$$

and since $g = 6/5p_m = 6/5\delta\theta R_2 = .236''$ say $15/64''$, h becomes $5/16''$. For $g + h = 35/64$ the number of turns would be $\frac{2}{2 \times 35/64} = 1.83$ ($\phi = 658°$). The actual spring constant is $\frac{2 \times 1.03 \times 30 \times 10^6 \times 3/4 \times (5/16)^3}{12 \times 9.20 \times 5} = 2560\,\#$ in/rad. The angle of twist $\theta = \frac{600}{2560} = .234$ rad. The nominal stress is given by (14):

$$\sigma^* = \frac{.234 \times 30 \times 10^6 \times 5/16}{2 \times 9.20 \times 5} = 23{,}800\,\#/\text{in.}^2$$

The stress concentration due to the limited number of turns is $\alpha_1 = 1.292$ (Fig. 3).

The maximum stress occurs at a radius $r_m = .825R_2$ (Fig. 14), which makes $r_m/h = \frac{4.125}{5/16} = 13.2$. The stress concentration due to curvature is then $\alpha_2 = 1.015$.

The total stress concentration factor is $1.292 \times 1.015 = 1.312$ and the actual stress is

$$1.312 \times 23{,}800 = 31{,}200 \#/\text{in.}^2$$

MOST FAVORABLE GAP.

The question arises whether (from a standpoint of stress) it is always favorable to make the gap as small as the motion permits. Without stress concentration it is obvious that the smallest gap (the largest volume of material) gives the lowest stress. Actually the answer depends on the stress concentration. Where the stress concentration decreases with increased coil length (for constant flexibility) the design with the smallest gap is undoubtedly the best one.

On those portions of the curve of Fig. 3 where $\frac{d\alpha_1}{d\phi}$ is positive, it is not obvious which is the best choice; low stress concentration or large spring volume.

The following example serves to illustrate this:

From Fig. 3 it is seen that the curve for α_1 is steepest for $\lambda = .4$ between 440° and 480°. We will, therefore, compare a spring of 440° with one of 480° (same spring constant).

Now the nominal stress is proportional to $\frac{1}{\sqrt[3]{a^2\beta}}$, so that neglecting the curvature effect the actual stress is proportional to

$$\frac{\alpha_1}{\sqrt[3]{a^2\beta}}.$$

Inserting numerical values we find:

$$\text{for } 440^\circ \quad \frac{\alpha_1}{\sqrt[3]{a^2\beta}} = \frac{1.415}{\sqrt[3]{6.15^2 \times 1.073}} = .4118,$$

$$\text{for } 480^\circ \quad \frac{\alpha_1}{\sqrt[3]{a^2\beta}} = \frac{1.512}{\sqrt[3]{6.70^2 \times 1.095}} = .4128,$$

so that as far as stress is concerned the two springs are about equivalent.

From this example we may conclude that in every practical case the spring with the smallest possible gap is equivalent to or better than any other design.

LIST OF NOTATIONS.

a, b, c, d, e, f—Non-dimensional constants (Appendix A).

E	Modulus of elasticity	lbs./in.^{2}
g	Gap between adjacent windings	in.
H	Radial force at outer end of spiral	lbs.
h	Thickness of coil	in.
I	Moment of inertia of coil in bending	in.^{4}
i	Number of spirals in one spring	
K	Spring constant of one spiral spring	lbs. in/rad.
K_i	Total spring constant of i spirals	lbs. in/rad.
l	Total length of spiral	in.
M	Bending moment at any point of coil	lbs. in.
M_m	Maximum bending moment	lbs. in.
M^*	Nominal bending moment $\theta EI/l$	lbs. in.
M_0	Bending moment at outer end of spiral	lbs. in.
$M_1 = PR_2$		lbs. in.
$M_2 = HR_2$		lbs. in.
M_i	Total torque on spring with i coils $= i(M_0 + M_1)$	lbs. in.
n	Number of turns per spiral	
P	Tangential force at outer end of spiral	lbs.
p	Radial deflection at any point	in.
R_1	Radius at inner end of spiral	in.
R_2	Radius at outer end of spiral	in.
R_m	Radius at which M is maximum	in.
r	Radius at any point	in.
S, T, U	Dimensionless constants (Appendix D).	
w	Width of coil	in.
y, z	Coordinates of point on spiral (Fig. 1)	in.
α	Total stress concentration	
α_1	Stress concentration due to limited number of turns	
α_2	Stress concentration due to "curved beam effect"	

β	Correction factor for spring constant	
θ	Total angle of deflection of spring	rad.
$\lambda = (R_2 - R_1)/R_2$		
$\eta = \lambda/\phi$		
φ	Angle from outer end of spiral to any point (Fig. 1)	rad.
φ_m	Angle at which bending stress is maximum	rad.
ϕ	Total angle from outer to inner end of spiral	rad.
χ	Variable angle between 0 and φ	rad.
σ	Stress in coil	lb./in.^{2}
σ^*	Nominal stress (due to M^*)	lb./in.^{2}

APPENDIX A.

Evaluation of Integrals a, b, c, d, e, f.

By writing $dl = rd\varphi$ in these integrals, only a very small error is introduced. (See Appendix B.) Furthermore we shall write $r = R_2(1 - \eta\varphi)$, according to the definition of the spiral

$$\eta = \frac{R_2 - R_1}{R_2\phi}$$

or

$$\eta = \frac{\lambda}{\phi}.$$

Noting from Fig. 1 that $y = R_2 - r\cos\varphi = R_2[1 - (1 - \eta\varphi)\cos\varphi]$ while $z = r\sin\varphi = R_2(1 - \eta\varphi)\sin\varphi$, our integrals become:

$$a = \int_0^\phi (1 - \eta\varphi)d\varphi = \phi - \eta\frac{\phi^2}{2} = \phi\left(1 - \frac{\lambda}{2}\right),$$

$$b = \int_0^\phi [1 - (1 - \eta\varphi)\cos\varphi](1 - \eta\varphi)d\varphi$$

$$= \phi - \sin\phi + \lambda\left(2\sin\phi + \frac{2\cos\phi}{\phi} - \frac{\phi}{2} - \frac{2}{\phi}\right)$$

$$+ \lambda^2\left(\frac{2\sin\phi}{\phi^2} - \sin\phi - \frac{2\cos\phi}{\phi}\right),$$

$$c = \int_0^{\phi} (1 - \eta\varphi)^2 \sin\varphi d\varphi$$

$$= 1 - \cos\phi + \lambda\left(2\cos\phi - \frac{2\sin\phi}{\phi}\right) + \lambda^2\left(\frac{2\sin\phi}{\phi} + \frac{2\cos\phi}{\phi^2} - \cos\phi - \frac{2}{\phi^2}\right).$$

$$d = \int_0^{\phi} [1 - (1 - \eta\varphi)\cos\varphi]^2(1 - \eta\varphi)d\varphi$$

$$= \frac{3}{2}\phi - 2\sin\phi + \frac{1}{2}\sin\phi\cos\phi + \lambda\left(4\sin\phi + \frac{4\cos\phi}{\phi} - \frac{5}{4}\phi - 4/\phi + \frac{3}{4}\frac{\sin^2\phi}{\phi} - \frac{3}{2}\sin\phi\cos\phi\right) + \lambda^2\left(\frac{4\sin\phi}{\phi^2} + \frac{\phi}{2} - 2\sin\phi - \frac{4\cos\phi}{\phi} + \frac{3}{2}\sin\phi\cos\phi + \frac{3}{4\phi} - \frac{3}{2}\frac{\sin^2\phi}{\phi} - \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi^2}\right) + \lambda^3\left(\frac{3}{4}\frac{\sin^2\phi}{\phi} + \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi^2} - \frac{\phi}{8} - \frac{\sin\phi\cos\phi}{2} - \frac{3}{8\phi} - \frac{3}{8}\frac{\sin^2\phi}{\phi^3}\right).$$

$$e = \int_0^{\phi} [1 - \eta\varphi]^3(\sin\varphi)^2 d\varphi = \frac{\phi}{2} - \frac{1}{2}\sin\phi\cos\phi + \lambda\left(\frac{3}{2}\sin\phi\cos\phi - \frac{3\phi}{4} - \frac{3}{4}\frac{\sin^2\phi}{\phi}\right) + \lambda^2\left(\frac{\phi}{2} - \frac{3}{2}\sin\phi\cos\phi - \frac{3}{4\phi} + \frac{3}{2}\frac{\sin^2\phi}{\phi} + \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi^2}\right) + \lambda^3\left(\frac{1}{2}\sin\phi\cos\phi - \frac{\phi}{8} + \frac{3}{8\phi} - \frac{3}{4}\frac{\sin^2\phi}{\phi} - \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi^2} + \frac{3}{8}\frac{\sin^2\phi}{\phi^3}\right).$$

$$f = \int_0^{\phi} [1 - (1 - \eta\varphi)\cos\varphi](1 - \eta\varphi)^2 \sin\varphi d\varphi$$

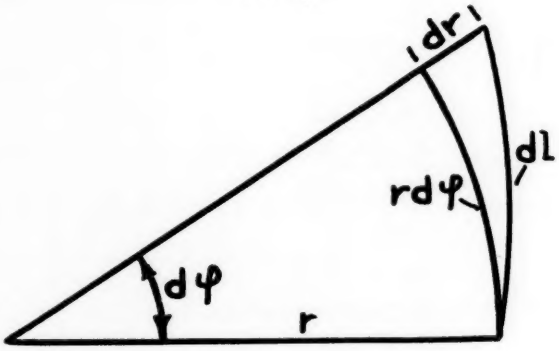
$$= 1 - \cos\phi - 1/2\sin^2\phi + \lambda\left(2\cos\phi - \frac{2\sin\phi}{\phi} - \frac{3}{4} + \frac{3}{2}\sin^2\phi + \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi}\right) + \lambda^2\left(\frac{2\sin\phi}{\phi} + \frac{2\cos\phi}{\phi^2} - \cos\phi - \frac{2}{\phi^2} + \frac{3}{4} - \frac{3}{2}\sin^2\phi - \frac{3}{2}\frac{\sin\phi\cos\phi}{\phi} + \frac{3}{4}\frac{\sin^2\phi}{\phi^2}\right) + \lambda^3\left(\frac{\sin^2\phi}{2} - \frac{1}{4} + \frac{3}{4}\frac{\sin\phi\cos\phi}{\phi} + \frac{3}{8\phi^2} - \frac{3}{4}\frac{\sin^2\phi}{\phi^2} - \frac{3}{8}\frac{\sin\phi\cos\phi}{\phi^3}\right).$$

APPENDIX B.

Error Introduced by Putting $dl = rd\varphi$.

The true value for *dl* (Fig. 19) is

FIG. 19.



$$dl = \sqrt{r^2 + \left(\frac{dr}{d\varphi}\right)^2}\, d\varphi$$

or since $r = R_2(1 - \eta\varphi)$ and

$$\frac{dr}{d\varphi} = -\eta R_2$$

$$dl = R_2 d\varphi \sqrt{(1 - \eta\varphi)^2 + \eta^2}.$$

Using this true value makes the direction integration of $a \cdots f$ so hard that it probably could only be performed graphically under great difficulties.

Therefore we write $dl = rd\varphi = R_2(1 - \eta\varphi)d\varphi$ and our error consists in replacing $\sqrt{(1 - \eta\varphi)^2 + \eta^2}$ by $1 - \eta\varphi$. The error is largest for a small number of turns. Taking for example $\phi = 2\pi$ (one turn only), $\lambda = .5$; $\eta = \frac{.5}{2\pi} = .0796$; we have:

for $\varphi = 0$: $\sqrt{1 + \eta^2} = 1.003$ instead of 1.000 or 0.3% error,
$\varphi = \pi$: $\sqrt{.75 + \eta^2} = .754$ instead of .750 or 0.5% error,
for $\varphi = 2\pi$: $\sqrt{.5 + \eta^2} = .506$ instead of .500 or 1.2% error.

It follows that for all practical considerations the error produced by putting $dl = rd\varphi$ can be neglected.

APPENDIX C.

Location of Maximum Moment.

For the location of the maximum moment we have:

$$\frac{dM}{d\varphi} = 0, \qquad \text{or since} \qquad M = M_0 + M_1\frac{y}{R_2} + M_2\frac{z}{R_2}$$

$$\frac{d}{d\varphi}\{M_0 + M_1[1 - (1 - \eta\varphi)\cos\varphi] + M_2(1 - \eta\varphi)\sin\varphi\} = 0.$$

This gives for φ_m (the angle at which the moment is a maximum):

$$\frac{M_1}{M^*}\{\phi\sin\varphi_m + \lambda(\cos\varphi_m - \varphi_m\sin\varphi_m)\}$$
$$+ \frac{M_2}{M^*}\{\phi\cos\varphi_m - \lambda(\varphi_m\cos\varphi_m + \sin\varphi_m)\} = 0.$$

Naturally all the angles φ for which the moment is a maximum or a minimum, satisfy the above equation. We are interested in that angle for which the moment is an absolute maximum.

The maximum stress is at an angle of approximately 270° from the outer end of the coil (Fig. 16)

APPENDIX D.

Evaluation of the Integrals S, T and U.

These integrals have the following values:

$$S = 1 - \cos\varphi + 2\eta[\sin\varphi - \varphi] + \eta^2[\varphi^2 - 2 + 2\cos\varphi],$$

$$T = S - V\sin\varphi + W\cos\varphi, \text{ and}$$

$$U = X + V\cos\varphi + W\sin\varphi, \text{ where}$$

$$V = \frac{\sin 2\varphi}{4} + \frac{1}{2}\varphi + \frac{3\eta}{4}[\sin^2\varphi - \varphi^2 - \varphi\sin 2\varphi]$$
$$+ \frac{3\eta^2}{4}\left[\frac{2}{3}\varphi^2 + \varphi^2\sin 2\varphi + \varphi\cos 2\varphi - \frac{1}{2}\sin 2\varphi\right]$$
$$- \frac{\eta^3}{4}\left[\frac{\varphi^4}{2} + \varphi^3\sin 2\varphi + \frac{3}{2}\varphi^2\cos 2\varphi\right.$$
$$\left. - \frac{3}{2}\varphi \times \sin 2\varphi + \frac{3}{2}\sin^2\varphi\right],$$

$$W = \frac{\sin^2\varphi}{2} + \frac{3\eta}{4}\left[\varphi\cos 2\varphi - \frac{1}{2}\sin 2\varphi\right]$$
$$+ \frac{3\eta^2}{4}[-\varphi^2\cos 2\varphi + \varphi\sin 2\varphi - \sin^2\varphi]$$
$$+ \frac{\eta^3}{4}[\varphi^3\cos 2\varphi - \frac{3}{2}\varphi^2\sin 2\varphi - \frac{3}{2}\varphi\cos 2\varphi$$
$$+ \frac{3}{4}\sin 2\varphi],$$

$$X = \cos\varphi\left(-\varphi + \frac{3}{2}\eta\varphi^2 - \eta^2\varphi^3 + \frac{\eta^3\varphi^4}{4}\right).$$

Industrial Manufacture of Krypton and Xenon.—(*Engineering*, Vol. CXLIV, No. 3745.) The utilization of krypton and xenon in incandescent lamps has for some time been looked upon as a very expensive practice, even though the efficiency of the lamps would be much increased thereby. These gases are contained in air in very small quantities. Hundreds of millions of incandescent lamps are made annually, and the employment of krypton, even on a very small scale, would necessitate an annual production of several hundred cubic meters of the gas. It has been obtained as a by-product of the manufacture of oxygen and nitrogen but this method does not insure a sufficient supply. A process devised and patented by La Societe L'Air Liquide extracts krypton and xenon from the air, not as by-products but as main products, and in sufficient quantity to meet requirements. While, in order to obtain oxygen or nitrogen from the air it is necessary to liquefy the air completely, in extracting krypton and xenon it is only necessary to cool the air to the dew point and pass it through a rectification column in counter current to a very small quantity of liquid air. In practice the amount of washing liquid is of considerable importance but it is expected that improvements in the columns will allow the quantity to be reduced. The operation of the process is greatly facilitated by the employment of cold regenerators working alternately on the Frankl system. These regenerators render it possible to avoid pre-purification of the air (Drying and removal of CO_2). Apparatus has been erected and undergone preliminary tests at the Boulogne works of the concern. It has a capacity of 30,000 cub. m. per hour of air compressed to 0.7 atm. The energy consumption is estimated at 40 horsepower hours per litre of xenon and krypton mixed in the proportion on which the gases exist in the atmosphere.

R. H. O.

THE FORMATION OF SYSTEMS OF UNITS.[1]

BY

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INTRODUCTION.

The recent action of the I. E. C.[2] has brought forth numerous and divergent points of view with regard to the number of fundamental quantities that are required to establish a system of units. Philosophically most of these points of view are justifiable, and the choice among them is arbitrary as far as logic is concerned. The choice among them must therefore be made on a basis of utility rather than of correctness.

Systems of units, in which all measurements can be based on a minimum number of arbitrary standards, and in which unit magnitudes of various quantities are directly related by equations involving no arbitrary numerical factors, are found to have many practical advantages. This paper presents a simple method for formulating such self-consistent systems of units for the physical quantities in all branches of physics and engineering.

The principles are set forth that determine the necessary and sufficient number of fundamental quantities for any such system of units. Although these principles are quite generally applied in the case of translational mechanics, they are rarely explicitly stated, and they are still more rarely consistently applied to include the units for quantities in other

[1] This paper grew out of work done by the author in connection with the course revision program of the Department of Electrical Engineering of the Massachusetts Institute of Technology. Permission has been granted by the Institute to reproduce the accompanying tables and certain small portions of the 1936 copyrighted edition of the Course 6.00 Notes "Principles of Electrical Engineering." The author wishes to acknowledge his indebtedness to the several members of the staff who have contributed to this material on units and in particular to Professors Hazen and Bowles for their valuable suggestions during the preparation of the paper.

[2] A. E. Kennelly, "I. E. C. Adopts MKS System of Units," *Elect. Engrg.*, 54: 1373, December 1935.

branches of physics. The method is therefore illustrated by the development of a system of units for translational mechanics, and is then extended to include a number of other fields.

Next, in order to make the dimensions of physical quantities as useful as possible, it is found desirable to attach actual physical significance to them. The formulation of systems of units as herein described aids greatly in this connection. In consideration of the number of conflicting points of view regarding the significance of dimensions, the arbitrariness of this procedure is admitted at the outset.

Finally, comprehensive charts of units in several systems are included to illustrate in tabular form the development of systems of units and their interrelations, as described in the paper. These tables give the dimensions of the quantities and the conversion factors relating their units in a number of systems in common use, and should be of particular value not only to students but also to others, particularly those who find it necessary to use units in practical problems.

ARBITRARY AND SELF-CONSISTENT SYSTEMS OF UNITS.

In order to make possible the measurement or the quantitative description of anything a certain definite amount of each quantity in terms of which the thing is described must be specified as a unit for that quantity. A standard must in turn be specified for each unit. The unit for each quantity and the standard for the unit can be chosen arbitrarily, independently of the relations among the different quantities, or units of a minimum possible number of quantities can be considered fundamental, and units for all others defined in terms of them.

If the first is done, a numerical constant must be included as a factor in every equation expressing a relationship among different quantities. For example, if the U. S. gallon is taken as an arbitrary unit of volume and the inch is taken as an arbitrary unit of length, the volume of a box whose faces are normal planes and whose edges are of length L_1 inches, L_2 inches, and L_3 inches is found to be:

$$V = \frac{1}{231} L_1 L_2 L_3 \text{ units (gallons).}$$

In this case the constant 1/231 arises solely from the use of arbitrary units. In addition to the inconvenience of keeping track of the numerical constant which may be considerable if very many different quantities are involved, there are two more serious disadvantages to this procedure. First, the constant must be determined experimentally and is always liable to experimental error. Secondly, the "constant" may change with time, for no matter how carefully standards of the inch and of the gallon might be constructed and maintained there would always be the possibility of these standards changing slightly due to aging.

The obvious way to overcome these objections is to follow the second plan, and to consider the units of a minimum possible number of quantities as fundamental and to define all others in terms of them. Thus if the unit of volume is defined in terms of the unit of length, for example as a cube whose edges are of unit length, the volume of the above box, the length of whose sides are measured in inches, becomes simply:

$$V = L_1 L_2 L_3 \text{ units (cubic inches)}.$$

The elimination of the numerical constant eliminates the difficulties attending its use.

A group of units of different physical quantities built up in this way through the equations relating the different quantities, written without arbitrary constants of proportionality, is called a self-consistent system of units, or frequently simply a system of units. Hereafter in this paper the term system will be understood to mean such a self-consistent system, unless otherwise noted.

Attention should be called at this point to the "specific" units, such as specific heat and specific gravity. These units belong to no system in the above sense of the term, for an arbitrary standard is required for each quantity considered. Thus the heat capacity per unit volume of water and the force of gravity on a unit volume of water are generally used as the standards for the two units mentioned. Since any specific measure simply expresses a numerical ratio of the magnitude of a physical quantity to the magnitude of the like physical quantity of a reference standard, specific quantities are ordinarily considered to be numerics, i.e., to have

no dimensions. This distinction between specific and other units appears to be arbitrary, for no other measure tells any more or any less. If the distinction must be made, however, care should be used in employing "specific" quantities in equations with other quantities. More will be said about this later in the section on dimensions.

NUMBER OF FUNDAMENTAL UNITS FOR A SELF-CONSISTENT SYSTEM.

The number of fundamental units required in any branch of physics will next be considered. This number is fixed by the number of separate physical quantities recognized in that branch of physics and by the number of independent relations to be considered among them. The number of physical quantities that are recognized as separate and distinct is largely a matter of convenience of thought; furthermore, the number of independent relations to be considered among these quantities is not fixed, but may change from time to time as more knowledge is accumulated. In general, it would appear that each branch of physics is characterized by one or more quantities unique to that branch, which cannot be described completely in terms of quantities common to the other branches. The number of equations considered is not necessarily the total number known. For example, it is customary when building up a system of units for mechanics to omit the gravitational equation:

$$f = \frac{m_1 m_2}{r^2},$$

from the relations considered among mass, length, and time.

The thing described may be a physical body, requiring for its description such quantities as mass, length, volume, and density; it may be a motion, requiring for its description such quantities as time and velocity; it may be a more abstract conception, such as a magnetic field, which requires magnetic field intensity for its description. In certain instances, notably in the case of light and sound, certain quantities describe subjective rather than objective phenomena, e.g., the response of the human ear to sound energy flux. Standards representing these subjective phenomena are defined, however, so that measurements involving them can be

made objectively. Hence, to this extent at least, they are legitimately included in a tabulation of physical quantities.

Once the quantities that are recognized as separate and distinct have been specified, and the relations that are to be considered among them have been stated, the number of quantities that must be considered fundamental is not arbitrary but is determined as shown below.

TRANSLATIONAL KINEMATICS.

Consider, for example, the simple case of translational kinematics. The fundamental processes can be described by a statement of the relations among four quantities, distance, L, time, t, velocity, v, and acceleration, a. These four quantities are related by two independent equations:

$$v = \frac{dL}{dt}, \qquad a = \frac{dv}{dt}. \tag{1}$$

It is known that if n quantities are related by m independent equations, any m of the quantities can be expressed in terms of the remaining $n - m$ quantities. In the case under consideration $n = 4$, $m = 2$, and $n - m = 2$. Hence any two of the quantities can be expressed in terms of the remaining two. Quantitatively, this means that the magnitude or the extent of two of the quantities can be expressed in terms of the units of the other two. Thus velocity can be measured in terms of length and time, and a unit for velocity can be defined in terms of a unit of length and a unit of time, viz., centimeter per second. It follows that if the magnitudes of the units for any two quantities are specified, the magnitudes of the units for the remaining two quantities are fixed by the equations. Thus the equations that describe the relations among the four physical quantities serve also to define the units of two of them. Note that no arbitrary factors are included in equations (1). Only the actual physical quantities are allowed to appear.

The choice of fundamental quantities in the above group may be made arbitrarily. Of the four quantities considered, length and time are generally chosen.

TRANSLATIONAL KINETICS.

Next consider translational kinetics. The addition of the concepts of force, f, work, W, and mass, m, to the concepts of length, time, velocity, and acceleration of kinematics will be sufficient. There are two additional independent equations relating these quantities:

$$\begin{aligned} f &= \frac{d}{dt}(mv), \\ W &= \int f dL. \end{aligned} \tag{2}$$

There are now 7 quantities related by 4 equations. Hence one more quantity must be considered fundamental and a standard specified for it. Mass is generally chosen.

Substantially all systems of units used in scientific and engineering work include as fundamental units those of mass, length, and time. Such systems are called *absolute systems* and the corresponding units *absolute units*.

ROTATIONAL KINEMATICS AND KINETICS.

A parallel development in rotational kinematics and kinetics leads to the need for one more fundamental quantity. Angle, θ, angular velocity, ω, angular acceleration, α, torque, τ, and moment of inertia, I, replace distance, velocity, acceleration, force, and mass respectively in the above equations:

$$\begin{aligned} \omega &= \frac{d\theta}{dt}, \\ \alpha &= \frac{d\omega}{dt}, \\ \tau &= I\alpha, \\ W &= \int \tau d\theta. \end{aligned} \tag{3}$$

Thus five new quantities and only four new equations are added, or one more quantity than equation. It follows that one more quantity must be assumed to be fundamental, and an arbitrary standard agreed on for it. Angle is usually chosen.

In engineering work the unit of angle that is generally used, the radian, is that angle which subtends an arc equal

in length to the radius of the arc. This definition of a unit of angle is often taken to define the quantity angle as the ratio of two lengths. For most engineering work it is more desirable to define angle in terms of work and torque as outlined above. With angle defined and related to the other mechanical quantities in that way, arc can in turn be defined as the product of radius (length) and angle. Thus to be consistent with the system being developed, arc, or length along an arc, is to be considered as a physical quantity different from simple length. The unit of angle, the radian, is accordingly here given in terms of arc divided by length, instead of length divided by length.

THERMODYNAMICS.

The addition of one equation to those of mechanics will suffice to introduce thermodynamics for the purposes of this paper. Heat, H, which is accepted as a form of energy, thermal capacity, C, and temperature, θ, are related by the equation:

$$H = \int C d\theta. \tag{4}$$

Thus two new quantities are introduced by one equation, and according to the rules already established one of these must be chosen as fundamental. Temperature is generally chosen.

This conception of temperature as a separate physical quantity is not in conflict with the definition of temperature in terms of the energy of a perfect gas, for it will be noted that any such definition involves something more than just energy.

LIGHT.

Light requires the addition of still another fundamental quantity, for two new quantities, luminous flux F and visibility v, are related to radiant power P by one equation:

$$F = Pv. \tag{5}$$

Either of these two quantities F or v could be considered fundamental. Visibility is the one chosen, and an arbitrary standard [3] is set up for it. This standard is intended to rep-

[3] See "Handbook of Chemistry and Physics," 20th edition, pp. 1472 and 1605.

resent the average normal human eye, in such a way that luminous flux density (illumination) becomes a measure of the magnitude of the effect of light on the eye.

SOUND.

In sound, the relationship among the quantities involved is analogous to the case of light. Sound intensity I is the rate of flow of sound energy perpendicularly through any surface, per unit area of surface. Loudness is a measure of the magnitude of the effect of sound on the human ear. Loudness and sound intensity are related in a manner similar to that relating luminous flux and radiant power.[4] There is no accepted term for the quantity relating them, but, by analogy with visibility, the term "audibility" might be given this specific meaning. Thus:

$$\text{Loudness} = \text{sound intensity} \times \text{audibility}. \qquad (6)$$

Both the relation between sound intensity and the magnitude of the effect of sound on the ear, and the relation between radiant power density and the magnitude of the effect of light on the eye are actually very complicated functions, depending on the quality of the sound and light. This does not preclude setting up a simple arbitrary standard of visibility, however, or of "audibility." As more is learned about these quantities, it is reasonable to suppose that their standards will be redefined more precisely. Or visibility and audibility may themselves be defined in terms of a number of other more "fundamental" quantities.[5]

ELECTRODYNAMICS.

Electrical units may be introduced in the same manner as the units for other branches of physics already discussed. Three electrical quantities, charge Q, electric field intensity, $\mathcal{E}$, and magnetic induction, B, are related to the quantities of mechanics by two equations:

$$f = Q\mathcal{E}, \qquad (7)$$

$$f = Q(v \times B), \qquad (8)$$

[4] See Fletcher, "Speech and Hearing," p. 230. Van Nostrand, '29.

[5] For example, see Fletcher, H., and W. A. Munson, "Loudness, Its Definition, Measurement and Calculation," *J. A. S. A.*, **5**: 82, 1933.

wherein v is the velocity of the charge Q, and x indicates the vector or cross product. One possible procedure at this point would be to choose one of the above three electrical quantities as fundamental, and to derive the units for all other electrical quantities in terms of that electrical quantity together with mass, length, and time. This procedure has not as yet been universally agreed on, largely because of the difficulties involved in the establishment of a suitable arbitrary standard for any of the above electrical quantities. Six more equations may be written, therefore, introducing as many more new quantities: [6, 7]

$$Q = \int \rho dv, \tag{9}$$

$$\nabla \times H = 4\pi j + \frac{\partial}{\partial t} D, \tag{10}$$

$$\nabla \times \mathcal{E} = -\frac{\partial}{\partial t} B, \tag{11}$$

$$\nabla \cdot D = 4\pi\rho, \tag{12}$$

$$B = \mu H, \tag{13}$$

$$D = \epsilon \mathcal{E}, \tag{14}$$

where ϵ = permittivity,
Q = change,
$\mathcal{E}$ = electric field intensity,
μ = permeability,
H = magnetic field intensity,
j = current density,
D = electric flux density (displacement),
B = magnetic induction (flux density),
ρ = electric charge density,
t = time,
v = volume,
$\nabla \cdot$ = divergence,
$\nabla \times$ = rotation or curl.

[6] In unrationalized form, but in a consistent system of units.

[7] The usually-accepted meanings will be assigned to the quantities considered. For a discussion of other possibilities, see A. Sommerfeld, *Physik. Zeit.*, 36: 814, 1935.

Equation 10 implies an additional relation between current density j and displacement D, which may better be expressed by equation 12 together with the additional relation:

$$j = -\frac{\partial}{\partial t}\rho. \tag{15}$$

With the addition of equations 9 to 15, equations 7 and 8 are no longer independent, so there are left eight independent relations among nine electrical quantities and the quantities of mechanics. In keeping with the established policy of this paper, some one of the nine quantities (or some other quantity involving them) must be chosen arbitrarily as fundamental. If permittivity ϵ is chosen the resulting system of units is called electrostatic; if permeability μ is chosen the resulting system is called electromagnetic.

DIMENSIONS OF PHYSICAL QUANTITIES.

So far, attention has been given only to the question of the number of fundamental quantities necessary in a system of units for any branch of physics. The *size* of the units must also be specified, but before proceeding to this question the significance of the dimensions of physical quantities should be pointed out, since the method of dimensions will be extremely useful in relating the sizes of corresponding units in different systems.

It has been shown above how units for quantities not chosen as fundamental can be built up from the units for those so chosen. The *dimensions* of a quantity, in turn, show the exponents with which the component quantities enter as factors. The dimensions of all quantities can be obtained in terms of the fundamental quantities of any system of units through the same fundamental equations of the system that served to define their units. Again it should be stressed that in writing the fundamental equations of the system no arbitrary factors, either with or without dimensions, are allowed to appear. Only the physical quantities actually involved enter. To be consistent with this point of view, there can be, by definition, no such thing as a "dimensionless" physical quantity.

In extending an already-existing system of units to include a new branch of physics, it has been shown that there may be certain quantities, the dimensions of which cannot be obtained uniquely in terms of the fundamental quantities of the system. Accordingly, these quantities cannot be measured in terms of the standards of the fundamental quantities of the system. This does not mean that these quantities are dimensionless. It means, rather, that the number of existing fundamental quantities is insufficient for the new branch of physics, and that one or more additional fundamental quantities must be arbitrarily chosen. Thus, in extending the units of kinematics to include kinetics, it is found that the dimensions of mass and of work cannot be uniquely specified in terms of length and time. This is not ordinarily considered to be a valid excuse for calling either mass or work a dimensionless numeric. Instead, mass is arbitrarily chosen as a new fundamental quantity, with the "dimensions of mass." The same argument is applied to angle in rotational mechanics, to temperature in thermodynamics, to visibility in light, to audibility in sound, and to permeability or permittivity in electrodynamics. The entire justification for this conception of dimensions is its practicability, for it makes possible the fullest use of dimensional analysis. If dimensions are defined in the manner described they become uniquely related to the physical quantities: all physical quantities have dimensions, no two quantities which are physically different have the same dimensions, and no quantity has more than one set of dimensions in terms of the same fundamental quantities. Thus if measurements are to be made of a particular quantity in terms of the fundamental quantities of a given system of units, the dimensions of that quantity show which standards must be chosen and how they are related to it.

In apparent contradiction to the above statements, a number of quantities that have the same dimensions are listed in the accompanying tables. This is because the things being measured, or some of their properties, are not recognized as distinct physical quantities. For example, the strength of a magnetic pole is measured by the flux emanating from it; hence, although magnetic pole and magnetic flux are listed as separate quantities, their dimensions are the same. Cur-

rent and magnetomotive force furnish another example. In this case the concept "turn" is introduced to differentiate the two quantities, as indicated by the name of the practical unit of magnetomotive force. "Turn" could be introduced into the dimensional expressions as an additional fundamental quantity if it were so desired; in general, however, the advantages to be gained by so doing do not warrant such a procedure. These cases illustrate the earlier statement that the number of things that will be considered as separate and distinct physical quantities is quite arbitrary.

To make clear the value of the foregoing conception of dimensions, some of the applications of dimensional considerations will be reviewed briefly. Equations and expressions giving dimensions are normally identified by enclosing the symbols in brackets, as illustrated in the following tabulation:

	Quantity.	Dimensional Expression.
Fundamental	Mass	$[M]$
	Length	$[L]$
	Time	$[T]$
Derived	Area	$[A] = [L^2]$
	Velocity	$[V] = [LT^{-1}]$
	Acceleration	$[a] = [LT^{-2}]$
	Force	$[F] = [MLT^{-2}]$

In these examples the dimensions of derived quantities are given in terms of the fundamental quantities. Any fundamental quantity can be replaced by any other quantity in a dimensional expression provided that fundamental quantity appears in the dimensional expression for the second quantity. From the dimensional expression for the second quantity, the dimensional expression for the fundamental quantity is obtained in terms of the second quantity and the remaining fundamental quantities. For example, to replace L by V in the expression for force:

$$\text{From } [V] = [LT^{-1}],$$
$$[L] = [VT].$$

Putting this value in the expression for force:

$$[F] = [MVTT^{-2}]$$
$$= [MVT^{-1}].$$

Other uses of dimensional considerations include: (1) the simple checking of equations for homogeneity; (2) the calculation of conversion factors corresponding to changes from one system of units to another; and (3) the correlation of the experimental results which are obtained in the study of a phenomenon whose physical nature is only partly known.

The first of these uses enables one to determine whether all the necessary factors have been properly included in formulating an equation. For, in any equation representing physical facts, only like quantities can be equated or added. As a simple example, in the equation

$$f = ma,$$

the equals sign is understood to mean that the product of mass times acceleration has the same physical nature as force; force must have the same *dimensions* as mass times acceleration.

The second use can be readily demonstrated. Let the dimensional formula for a quantity Q be

$$[Q] = [M^a L^b T^c].$$

If the size of the unit of mass be increased by a factor m, the size of the unit of Q will thereby be increased by a factor of m^a. This application applies only to self-consistent systems of units, as previously defined.

The third use is illustrated by the theory and application of models in the solution of complicated dynamic problems, such as those involving fluid flow and the forces set up by such flow.[8] With this review of dimensions, a conception, inconsistent with the dimensional theory here set forth, which has appeared consistently in the literature, and which has led to considerable confusion, should be pointed out. In thermodynamics, heat and temperature are frequently related to *specific heat* instead of to heat capacity. Thus

$$\text{Heat} = \text{volume} \times \text{specific heat} \times \text{temperature}.$$

It is then concluded that since specific heat is by definition dimensionless, it follows that heat (energy) per unit volume

[8] For further information and references to original papers on this subject see: Glazebrook, Dictionary of Applied Physics, article on "Dynamic Similitude," or Porter, "The Method of Dimensions," Methuen, 1933.

and temperature have the same dimensions. The correct statement involving specific heat is:

Heat = volume × specific heat × temperature × *heat capacity per unit volume of the reference standard of specific heat.*

This statement is in complete agreement with equation 5, and leads to the same results relative to dimensions.

Similar errors are frequently made in connection with specific inductive capacity and like quantities in electrodynamics.

SIZES OF UNITS.

In addition to specifying the quantities that shall be considered fundamental in any system of units, it is necessary to specify the magnitudes of the units for those so chosen, in terms of standards. Both the standard and the size of the unit, defined in terms of the standard, are arbitrary. In recent years most scientific work has used as fundamental units the centimeter, the gram, and the second, defined respectively in terms of the International Prototype Meter Bar, the International Prototype Kilogram, and the Mean Solar Day. The system of units based on these fundamental units is known as the absolute c.g.s. system. This name connotes two things, first that the fundamental quantities of the system are length, mass, and time, and secondly that the sizes of the units of those quantities are the centimeter, the gram, and the second. Note that the size of the unit is not the same as the size of the standard in terms of which it is defined in any of the above cases.

As branches of physics other than translational mechanics are introduced and additional fundamental quantities are specified, additional fundamental units must be chosen and their standards defined. If length, mass, and time are retained as three of the fundamental quantities in any such system, the name "absolute" may be retained, in accordance with general usage. If the centimeter, gram, and second are retained as the units of those quantities, the designation "absolute c.g.s." is retained. Other qualifying terms may be added to identify the additional fundamental quantities and their units.

The following are the generally accepted units and standards of the non-electrical fundamental quantities. The unit of angle is the radian, and its "standard" is a geometrical definition. The unit of temperature is the degree Kelvin, or Centigrade, defined in terms of the constant volume hydrogen gas thermometer and the temperature of the freezing and boiling points of water. The unit of visibility is the lumen per unit of power, defined in terms of a standard visibility curve which is intended to represent the response of the normal human eye. There is no name for the unit of audibility, but the generally accepted "standard" is the loudness-intensity relation as published by Fletcher.

The various electrical units, and their interrelations, will now be considered. Two systems have been mentioned thus far, the absolute electrostatic and the absolute electromagnetic. In the absolute c.g.s. electrostatic system the permittivity of free space is chosen for a standard of the fourth fundamental quantity, with a magnitude of unity. In the absolute c.g.s. electromagnetic system the permeability of free space is chosen for the standard of the fourth fundamental quantity with a magnitude of unity. Coulomb's law for electric charges or for magnetic poles:

$$f = \frac{Q_1 Q_2}{\epsilon r^2}, \tag{16}$$

$$f = \frac{m_1 m_2}{\mu r^2}, \tag{17}$$

is then used as the first step in relating the remaining electrical units to the fundamental ones. Thus unit charge in an electrostatic system of units is that charge which repels a like charge with unit force at unit distance in a medium of unit permittivity. In the absolute c.g.s. electrostatic system this means such a charge that the force is one dyne at one centimeter in free space. Similarly unit pole in an electromagnetic system of units is that pole which repels a like pole with unit force at unit distance in a medium of unit permeability. In the absolute c.g.s. electromagnetic system this implies a pole such that the force is one dyne at one centimeter in free space.

The order in which the remaining units are defined in each system is indicated in the accompanying table of units.

RELATION BETWEEN THE ELECTROSTATIC AND THE ELECTROMAGNETIC UNITS.

There is no way to determine the relative magnitudes of the units of the absolute c.g.s. electrostatic and of the absolute c.g.s. electromagnetic systems other than by experiment. The experiment need not be performed on each and every quantity, however, for the methods of dimensional manipulation outlined above furnish a means of determining the ratios of all units in the two systems, once the ratios of the fundamental units have been established. This is provided, of course, that dimensions have been assigned to all quantities as required, according to the method outlined. For example, let a current in a circuit be measured in electromagnetic units at one point and in electrostatic units at another. The same current which was measured as one electromagnetic unit would be measured as approximately 3×10^{10} electrostatic units. Thus the c.g.s. electromagnetic unit of current is approximately 3×10^{10} times the size of the c.g.s. electrostatic unit of current. Next the ratios of magnitudes of the fundamental units of the two systems should be found. From the dimensional expressions for current in the accompanying table

$$[\epsilon] = [I^2 M^{-1} L^{-3} T^4]$$

and

$$[\mu] = [I^{-2} M L T^{-2}].$$

According to the procedure outlined in the discussion of dimensions, the ratio of the magnitudes of the units for either ϵ or μ in the two systems can be found by replacing the quantities in their dimensional expressions by the ratio of the magnitudes of their units. The units for mass, length, and time in the two systems are the same. The ratio of the magnitudes of the units of current has just been given. Hence:

$$\frac{\text{Size of unit of permittivity, c.g.s. e.m.u.}}{\text{Size of unit of permittivity, c.g.s. e.s.u.}} = (3 \times 10^{10})^2,$$

$$\frac{\text{Size of unit of permeability, c.g.s. e.m.u.}}{\text{Size of unit of permeability, c.g.s. e.s.u.}} = \frac{1}{(3 \times 10^{10})^2}.$$

TABLE I.

QUANTITY	SYMBOL	CGS ELECTROMAGNETIC UNITS					CGS ELECTROSTATIC UNITS						QES UNITS		CGSS UNITS		GIORGI - MKS UNITS				ELECTRICAL DIMENSIONS $Q = R^a I^b L^c T^d$	QUANTITY
		DIMENSIONS $Q = M^a L^b T^c$ a b c	UNRATIONALIZED DEFINITION	UNRATIONALIZED NAME	RATIONALIZED NO. E.M.U. = ONE UNIT	SUBRATIONALIZED NAME	SUBRATIONALIZED NO. E.M.U. = ONE UNIT	DIMENSIONS $Q = M^a L^b T^c$ a b c	UNRATIONALIZED DEFINITION	UNRATIONALIZED NAME	UNRATIONALIZED NO. E.S.U. = ONE UNIT	RATIONALIZED NO. E.S.U. = ONE UNIT	SUBRATIONALIZED NAME	SUBRATIONALIZED NO. E.S.U. = ONE UNIT	SUBRATIONALIZED NAME	SUBRATIONALIZED NO. E.S.U. = ONE UNIT	UNRATIONALIZED NAME	UNRATIONALIZED NO. E.S.U. = ONE UNIT	SUBRATIONALIZED NAME	SUBRATIONALIZED NO. E.S.U. = ONE UNIT	a b c d	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	Permittivity	ϵ	0 -2 2 -1	$\frac{1}{4\pi}$ ÷ vel.	—	1	Abfarad / Cm	4π	0 0 0 1	Fundamental	—	6	$1/c^2$	H	$1/c^2$	Statfarad / cm	$4\pi/c^2$	Farad / Quadrant	$4\pi \cdot 10^{-18}$	Farad / Cm.	$4\pi \cdot 10^{-9}$	—	10^{-11}	Farad / Meter	$4\pi \cdot 10^{-9}$	$4\pi c^2 \cdot 10^{-11}$	-1 0 -1 1	Permittivity
2	Charge	Q	$\frac{1}{2}$ $\frac{1}{2}$ 0 $-\frac{1}{2}$	$\int I\,dT$	Abcoulomb	$1/\sqrt{4\pi}$	Abcoulomb	1	$\frac{1}{2}$ $\frac{1}{2}$ -1 $\frac{1}{2}$	$Q = \frac{Q_0}{\epsilon_r \mu_r} = f$	Statcoulomb	6	$1/c$	H	$1/c\sqrt{4\pi}$	Statcoulomb	$1/c$	Coulomb	10^{-1}	Coulomb	10^{-1}	Coulomb	10^{-1}	Coulomb	10^{-1}	$c \cdot 10^{-1}$	0 1 0 1	Charge
3	Charge density	ρ	$\frac{1}{2}$ $-\frac{3}{2}$ 0 $-\frac{1}{2}$	$Q = \int \rho\,dv$	Abcoulomb / Cm^3	$1/\sqrt{4\pi}$	Abcoulomb / Cm^3	1	$\frac{1}{2}$ $-\frac{3}{2}$ -1 $\frac{1}{2}$	$Q = \int \rho\,dv$	Statcoulomb / cm^3	6	$1/c$	H	$1/c\sqrt{4\pi}$	Statcoulomb / cm^3	$1/c$	Coulomb / $Quad^3$	10^{-28}	Coulomb / Cm^3	10^{-1}	Coulomb / $Meter^3$	10^{-7}	Coulomb / $Meter^3$	10^{-9}	$c \cdot 10^{-7}$	0 1 -3 1	Charge density
4	Current	I	$\frac{1}{2}$ $\frac{1}{2}$ -1 $-\frac{1}{2}$	$\int j \cdot da$	Abampere	$1/\sqrt{4\pi}$	Abampere	1	$\frac{1}{2}$ $\frac{1}{2}$ -2 $\frac{1}{2}$	$\frac{dQ}{dT}$	Statampere	6	$1/c$	H	$1/c\sqrt{4\pi}$	Statampere	$1/c$	Ampere	10^{-1}	Ampere	10^{-1}	Ampere	10^{-1}	Ampere	10^{-1}	$c \cdot 10^{-1}$	0 1 0 0	Current
5	Current density	j	$\frac{1}{2}$ $-\frac{3}{2}$ -1 $-\frac{1}{2}$	$\frac{1}{4\pi} \int H \cdot dl = \int j \cdot da$	Abampere / Cm^2	$1/\sqrt{4\pi}$	Abampere / Cm^2	1	$\frac{1}{2}$ $-\frac{1}{2}$ -2 $\frac{1}{2}$	$\frac{dI}{da_\perp}$	Statampere / cm^2	6	$1/c$	H	$1/c\sqrt{4\pi}$	Statampere / cm^2	$1/c$	Ampere / $Quad^2$	10^{-19}	Ampere / Cm^2	10^{-1}	Ampere / $Meter^2$	10^{-5}	Ampere / $Meter^2$	10^{-5}	$c \cdot 10^{-5}$	0 1 -2 0	Current density
6	Electric field intensity	$\mathcal{E}$	$\frac{1}{2}$ $\frac{1}{2}$ -2 $\frac{1}{2}$	$\oint E \cdot dl = -\frac{1}{c}\frac{d\Phi}{dt}$ flux	Abvolt / Cm	$\sqrt{4\pi}$	Abvolt / cm	1	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $-\frac{1}{2}$	$\int E \cdot dL$	Statvolt	6	c	H	$c\sqrt{4\pi}$	Statvolt / cm	c	Volt / Quad.	10^{-1}	Volt / Cm.	10^8	Volt / Meter	10^6	Volt / Meter	10^6	$10^6/c$	1 1 1 0	Electric field intensity
7	Potential difference	E	$\frac{1}{2}$ $\frac{1}{2}$ -2 $\frac{1}{2}$	$\int \mathcal{E} \cdot dl$	Abvolt	$\sqrt{4\pi}$	Abvolt	1	$\frac{1}{2}$ $\frac{1}{2}$ -1 $-\frac{1}{2}$	$\int \mathcal{E} \cdot dL$	Statvolt	6	c	H	$c\sqrt{4\pi}$	Statvolt	c	Volt	10^8	Volt	10^8	Volt	10^8	Volt	10^8	$10^8/c$	1 1 0 0	Potential difference
8	Displacement (elect. flux dens.)	D	$\frac{1}{2}$ $-\frac{1}{2}$ 0 $-\frac{1}{2}$	$\mathcal{E}\epsilon$	—	$\sqrt{4\pi}$	Abcoulomb / Cm^2	4π	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $\frac{1}{2}$	$\epsilon\mathcal{E}$	—	6	$1/c$	H	$\sqrt{4\pi}/c$	Statcoulomb / cm^2	$4\pi/c$	Coulomb / $Quad^2$	$4\pi \cdot 10^{-19}$	Coulomb / Cm^2	$4\pi \cdot 10^{-1}$	—	10^{-5}	Coulomb / $Meter^2$	$4\pi \cdot 10^{-5}$	$4\pi c \cdot 10^{-5}$	0 1 -2 1	Displacement
9	Electric flux	Ψ	$\frac{1}{2}$ $\frac{1}{2}$ 0 $-\frac{1}{2}$	$\int D \cdot da$	—	$\sqrt{4\pi}$	Abcoulomb	4π	$\frac{1}{2}$ $\frac{3}{2}$ -1 $\frac{1}{2}$	$\int D \cdot dA$	—	6	$1/c$	H	$\sqrt{4\pi}/c$	Statcoulomb	$4\pi/c$	Coulomb	$4\pi \cdot 10^{-1}$	Coulomb	$4\pi \cdot 10^{-1}$	—	10^{-1}	Coulomb	$4\pi \cdot 10^{-1}$	$4\pi c \cdot 10^{-1}$	0 1 0 1	Electric flux
10	Polarization	P	$\frac{1}{2}$ $-\frac{1}{2}$ 0 $-\frac{1}{2}$	$\frac{1}{4\pi}(D - \mathcal{E}\epsilon_0)$	Abcoulomb / Cm^2	$1/\sqrt{4\pi}$	Abcoulomb / Cm^2	1	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $\frac{1}{2}$	$\frac{1}{4\pi}(D - \epsilon_0 \mathcal{E})$	Statcoulomb / cm^2	6	$1/c$	H	$1/c\sqrt{4\pi}$	Statcoulomb / cm^2	$1/c$	Coulomb / $Quad^2$	10^{-19}	Coulomb / Cm^2	10^{-1}	Coulomb / $Meter^2$	10^{-5}	Coulomb / $Meter^2$	10^{-5}	$c \cdot 10^{-5}$	0 1 -2 1	Polarization
11	Resistance	R	0 1 -1 1	E/I	Abohm	4π	Abohm	1	0 -1 1 -1	E/I	Statohm	6	c^2	H	$4\pi c^2$	Statohm	c^2	Ohm	10^9	Ohm	10^9	Ohm	10^9	Ohm	10^9	$10^9/c^2$	1 0 0 0	Resistance
12	Resistivity	ρ	0 2 -1 1	E/j	Abohm·cm	4π	Abohm·cm	1	0 0 1 -1	E/j	Statohm·cm	6	c^2	H	$4\pi c^2$	Statohm·cm	c^2	Ohm-quad	10^{18}	Ohm·cm	10^9	Ohm-meter	10^{11}	Ohm-mtr	10^{11}	$10^{11}/c^2$	1 0 1 0	Resistivity
13	Conductance	G	0 -1 1 -1	1/R	Abmho	$1/4\pi$	Abmho	1	0 1 -1 1	1/R	Statmho	6	$1/c^2$	H	$1/4\pi c^2$	Statmho	$1/c^2$	Mho	10^{-9}	Mho	10^{-9}	Mho	10^{-9}	Mho	10^{-9}	$c^2 \cdot 10^{-9}$	-1 0 0 0	Conductance
14	Conductivity	γ	0 -2 1 -1	$1/\rho$	Abmho / cm	$1/4\pi$	Abmho / cm	1	0 0 -1 1	$1/\rho$	Statmho / cm	6	$1/c^2$	H	$1/4\pi c^2$	Statmho / cm	$1/c^2$	Mho / Quad	10^{-18}	Mho / cm.	10^{-9}	Mho / Meter	10^{-11}	Mho / Meter	10^{-11}	$c^2 \cdot 10^{-11}$	-1 0 -1 0	Conductivity
15	Capacitance	C	0 -1 2 -1	Q/E	Abfarad	$1/4\pi$	Abfarad	1	0 1 0 1	Q/E	Statfarad	6	$1/c^2$	H	$1/4\pi c^2$	Statfarad	$1/c^2$	Farad	10^{-9}	Farad	10^{-9}	Farad	10^{-9}	Farad	10^{-9}	$c^2 \cdot 10^{-9}$	-1 0 0 1	Capacitance
16	Elastance	S	0 1 -2 1	1/c	Abdaraf	4π	Abdarad	1	0 -1 0 -1	1/C	Statdarat	6	c^2	H	$4\pi c^2$	Statdaraf	c^2	Daraf	10^9	Daraf	10^9	Daraf	10^9	Daraf	10^9	$10^9/c^2$	1 0 0 -1	Elastance
17	Magnetic pole	m	$\frac{1}{2}$ $\frac{1}{2}$ -1 $\frac{1}{2}$	$\frac{m_1 m_2}{\mu r^2} = f$	Pole	H	$1/4\pi$	Maxwell	$1/4\pi$	$\frac{1}{2}$ $\frac{1}{2}$ 0 $-\frac{1}{2}$	$\frac{m_1 m_2}{\mu r^2} = f$	—	c		$c/\sqrt{4\pi}$	—	$c/4\pi$	Weber	$10^9/4\pi$	Weber	$10^9/4\pi$	—	10^9	Weber	$10^9/4\pi$	$10^9/4\pi c$	1 1 0 1	Magnetic pole
18	Permeability	μ	0 0 0 1	Fundamental	Gauss / Oersted	H	1	Abhenry / Cm.	$1/4\pi$	0 -2 2 -1	$\frac{1}{\epsilon_r \mu_r c^2}$ ÷ vel.	—	c^2		c^2	Stathenry / cm	$c^2/4\pi$	Henry / Quad.	$1/4\pi$	Henry / Cm.	$10^9/4\pi$	—	10^7	Henry / Meter	$10^7/4\pi$	$10^7/4\pi c^2$	1 0 -1 1	Permeability
19	Reluctivity	ν	0 0 0 -1	$1/\mu$	Oersted / Gauss	H	1	cm / Abhenry	4π	0 2 -2 1	$1/\mu$	—	$1/c^2$		$1/c^2$	cm / Stathenry	$4\pi/c^2$	Quad / Henry	4π	Cm. / Henry	$4\pi \cdot 10^{-9}$	—	10^{-7}	Meter / Henry	$4\pi \cdot 10^{-7}$	$4\pi c^2 \cdot 10^{-7}$	-1 0 1 -1	Reluctivity
20	Mag. moment	M	$\frac{1}{2}$ $\frac{1}{2}$ -1 $\frac{1}{2}$	m·l , Pole·cm	H	$1/4\pi$	Maxwell-cm	$1/4\pi$	$\frac{1}{2}$ $\frac{3}{2}$ 0 $-\frac{1}{2}$	m·l	—	c		$c/\sqrt{4\pi}$	—	$c/4\pi$	Weber·Quad.	$10^9/4\pi$	Weber-cm	$10^9/4\pi$	—	10^{10}	Weber·meter	$10^{10}/4\pi$	$10^{10}/4\pi c$	1 1 1 1	Mag. moment
21	Mag. field intensity	H	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $\frac{1}{2}$	f/m	Oersted	H	$\sqrt{4\pi}$	Abampere / cm	4π	$\frac{1}{2}$ $\frac{1}{2}$ -2 $\frac{1}{2}$	f/m	—	$1/c$		$\sqrt{4\pi}/c$	Statampere / cm	$4\pi/c$	Amp·turn / Quad.	$4\pi \cdot 10^{-10}$	Amp·turn / Cm	$4\pi \cdot 10^{-1}$	Praoersted	10^{-3}	Amp·turn / Meter	$4\pi \cdot 10^{-3}$	$4\pi c \cdot 10^{-3}$	0 1 -1 0	Mag. field intensity
22	Mag. induction (flux density)	B	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $\frac{1}{2}$	μH	Gauss	H	$\sqrt{4\pi}$	Gauss	1	$\frac{1}{2}$ $-\frac{1}{2}$ 0 $-\frac{1}{2}$	μH	—	c		$c\sqrt{4\pi}$	—	c	Weber / $Quad^2$	10^{-10}	Weber / Cm^2	10^8	Weber / $Meter^2$	10^4	Weber / $Meter^2$	10^4	$10^4/c$	1 1 -2 1	Mag. induction (flux density)
23	Magnetic flux	Φ	$\frac{1}{2}$ $\frac{1}{2}$ -1 $\frac{1}{2}$	$\int B \cdot da$	Maxwell	H	$\sqrt{4\pi}$	Maxwell	1	$\frac{1}{2}$ $\frac{1}{2}$ 0 $-\frac{1}{2}$	$\int B \cdot dA$	—	c		$c\sqrt{4\pi}$	—	c	Weber	10^8	Weber	10^8	Weber	10^8	Weber	10^8	$10^8/c$	1 1 0 1	Magnetic flux
24	Inductance	L	0 1 0 1	$E/\frac{dI}{dt}$	Abhenry	4π	Abhenry	1	0 -1 2 -1	$E/\frac{dI}{dt}$	Stathenry	6	c^2	H	$4\pi c^2$	Stathenry	c^2	Henry	10^9	Henry	10^9	Henry	10^9	Henry	10^9	$10^9/c^2$	1 0 0 1	Inductance
25	Magnetomotive force	$\mathcal{F}$	$\frac{1}{2}$ $\frac{1}{2}$ -1 $\frac{1}{2}$	$\int H \cdot dl$	Gilbert	H	$\sqrt{4\pi}$	Abampe-Turn	4π	$\frac{1}{2}$ $\frac{3}{2}$ -2 $\frac{1}{2}$	$\int H \cdot dl$	—	$1/c$		$\sqrt{4\pi}/c$	—	$4\pi/c$	Amp·turn	$4\pi \cdot 10^{-1}$	Amp·turn	$4\pi \cdot 10^{-1}$	Pragilbert	10^{-1}	Amp·turn	$4\pi \cdot 10^{-1}$	$4\pi c \cdot 10^{-1}$	0 1 0 0	Magnetomotive force
26	Reluctance	$\mathcal{R}$	0 -1 0 -1	$\mathcal{F}/\Phi$	Gilbert / Maxwell	H	1	Abampturn / Maxwell	4π	0 1 -2 1	$\mathcal{F}/\Phi$	—	$1/c^2$		$1/c^2$	—	$4\pi/c^2$	Amp·Turn / Weber	$4\pi \cdot 10^{-9}$	Amp·Turn / Weber	$4\pi \cdot 10^{-9}$	Pragilbert / Weber	10^{-9}	Amp·Turn / Weber	$4\pi \cdot 10^{-9}$	$4\pi c^2 \cdot 10^{-9}$	-1 0 0 -1	Reluctance
27	Permeance	P	0 1 0 1	1/R	Maxwell / Gilbert	H	1	Maxwell / Abamp Turn	$1/4\pi$	0 -1 2 -1	1/R	—	c^2		c^2	—	$c^2/4\pi$	Weber / Amp·turn	$10^9/4\pi$	Weber / Amp·turn	$10^9/4\pi$	Weber / Pragilbert	10^9	Weber / Amp·turn	$10^9/4\pi$	$10^9/4\pi c^2$	1 0 0 1	Permeance
28	Intensity of magnetization	J	$\frac{1}{2}$ $-\frac{1}{2}$ -1 $\frac{1}{2}$	M/vol.	Pole / Cm^2	H	$\sqrt{4\pi}$	Gauss	$1/4\pi$	$\frac{1}{2}$ $-\frac{1}{2}$ 0 $-\frac{1}{2}$	B - μ_0H	—	c		$c\sqrt{4\pi}$	—	$c/4\pi$	Weber / $Quad^2$	$10^{-10}/4\pi$	Weber / Cm^2	$10^8/4\pi$	—	10^4	Weber / $Meter^2$	$10^4/4\pi$	$10^4/4\pi c$	1 1 -2 1	Intensity of magnetization

The ratio of the sizes of all other units in the two systems can now be calculated by the same procedure, using the dimensional expressions for those quantities in terms of either ϵ or μ.

RATIONALIZATION.

It has been stated above that no arbitrary numerical constants are to be allowed in the equations defining the derived units in any system. However, it will be found in many cases that if the units for a group of quantities are defined in sequence with this restriction observed, various of the units will be related by other equations involving numerical constants.

By changing the order in which the unit quantities are defined, the numerical constants can be forced into other equations. In other words, numerical constants must be included in some of the equations relating unit quantities in any system, and, to a certain extent, the equations which contain the numerical constants can be chosen arbitrarily. In particular, if the electrical units are related by the equations 7 to 15, as has been done above, a factor 4π is forced to appear in certain equations that are much used in engineering. If the 4π is omitted from equations 10 and 12, thus:

$$\nabla \times H = j + \frac{\partial}{\partial t} D, \tag{10a}$$

$$\nabla \cdot D = \rho; \tag{12a}$$

this factor 4π can be relegated to certain less used equations. Omitting the 4π from these two equations will obviously change the size of certain of the units relative to the size of other units. Just which, if any, of the units will retain their original size is arbitrary to a degree, as shown below.

There are two methods which have been in general use to fix the size of the units. The first method, known as rationalization, leaves the units of μ and ϵ (as well as the units of M, L, and T) unchanged. This forces a change in the size of the unit of practically every other electrical quantity, as is shown in column 6 of Table I.

The second and more popular method increases the size of the unit of permittivity 4π times and decreases the size of

the unit of permeability by the same factor. This method, known as subrationalization, is just as effective in relegating 4π's to less used equations and leaves many more of the units unchanged in size. The effect of subrationalization on the size of the units is shown in Column 8 of Table I.

OTHER SYSTEMS OF ELECTRICAL UNITS.

1. Gaussian.

Because of the inconvenient sizes of some of the units of each of the above systems, many writers have preferred to use a mixed system, leaving the electric quantities in the c.g.s. electrostatic system and magnetic quantities in the c.g.s. electromagnetic system. This of course necessitates the introduction of a numerical factor in any equation containing both kinds of units. Of the equations so far listed, only two are affected, (10) and (11). In the mixed system these become:

$$\nabla \times H = \frac{1}{c}\left(4\pi j + \frac{\partial}{\partial t} D\right), \tag{10'}$$

$$\nabla \times \mathcal{E} = -\frac{1}{c}\frac{\partial}{\partial t} B, \tag{11'}$$

in which

$$c = 3.10^{10}.$$

This mixed system is known as the Gaussian System. In the tabulation of units, Table I, the letter *G* in column 5 or 12 indicates the use of that unit in this system. The rationalized Gaussian System is known as the Heaviside-Lorentz System, after its principal advocates. The Heaviside-Lorentz units are indicated in Table I by the letter *H* in column 6 or 13.

2. Practical Systems of Units.

All the systems of electrical units discussed thus far yield units which are rather awkward in size for most engineering work. A number of other systems have been proposed from time to time that yield more convenient magnitudes for the more commonly used units. Most of these systems are based on the electromagnetic system, changing the c.g.s. units of this system by various powers of ten, and yielding the ampere, ohm, volt, watt, coulomb, joule, farad, and henry for

	QUANTITY	SYMBOL	DIMENSIONS $Q = M^a L^b T^c$ a b c	DEFINITION	CGS NAME	MKS NAME	MKS CGS UNITS IN ONE UNIT	QES NAME	QES CGS UNITS IN ONE UNIT	CGSS NAME	CGSS CGS UNITS IN ONE UNIT	FOOT-SLUG-SECOND NAME	FOOT-SLUG-SECOND CGS UNITS IN ONE UNIT
	TRANSLATIONAL MECHANICS												
1	Mass	M	1 0 0	Fundamental	Gram	Kilogram	10^3	Gram-ft$^{3/2}$	10^{-11}	Gram-1	10^7	Slug	14594
2	Length	L	0 1 0	Fundamental	Centimeter	Meter	10^2	Quadrant	10^9	cm.	1	Foot	30.4801
3	Time	T	0 0 1	Fundamental	Second	Second	1	Second	1	second	1	Second	1
4	Area	A	0 2 0	L^2	cm^2	Meter^2	10^4	Quad^2	10^{18}	cm^2	1	Square ft.	929.0
5	Volume	V	0 3 0	L^3	cm^3	Meter^3	10^6	Quad.^{3}	10^{27}	cm^3	1	Cubic ft.	28317.
6	Density	δ	1 -3 0	M/V	gm/cm^3	Kg/m^3	10^{-3}	$\frac{gram\text{-}ft^{3/2}}{Quad.^3}$	10^{-38}	$\frac{gram\text{-}1}{cm^3}$	10^7	$slug/ft^3$	0.5154
7	Velocity	v	0 1 -1	dL/dT	cm/sec	$\frac{Meter}{sec}$	10^2	$\frac{Quad}{sec}$	10^9	cm/sec	1	ft./sec.	30.4801
8	Acceleration	a	0 1 -2	dv/dT	cm/sec^2	$\frac{Meter}{sec^2}$	10^2	$\frac{Quad}{sec^2}$	10^9	cm/sec^2	1	ft/sec^2	30.4801
9	Force	f	1 1 -2	M a	Dyne	Dyne-5	10^5	$\frac{Joule}{Quad.}$ (= dyne$^{1/2}$)	10^{-2}	Dyne-1	10^7	Pound	444820
10	Pressure	p	1 -1 -2	f/a	$Dyne/cm^2$	$\frac{Dyne\text{-}5}{meter^2}$	10	$\frac{Dyne\ 1/2}{Quad^2}$	10^{-20}	$\frac{Dyne\text{-}1}{cm^2}$	10^7	$\frac{Pound}{ft^2}$	478.80
11	Work or energy	W	1 2 -2	f · L	Erg	Joule	10^7	Joule	10^3	Joule	10^7	ft.-lb	1.35582×10^7
12	Action	α	1 2 -1	W · T	Erg·sec	Joule·sec	10^7	Joule·sec	10^3	Joule·sec	10^7	ft lb·sec	1.35582×10^7
13	Momentum	—	1 1 -1	M · v	$\frac{gm \cdot cm}{sec}$	$\frac{Kg \cdot m}{sec}$	10^5	—	10^{-2}	$\frac{gm \cdot cm}{sec.}$	10^7	$\frac{slug\ ft}{sec}$	44482.0
14	Power	P	1 2 -3	W/T	Erg/sec	Watt	10^7	Watt	10^7	watt	10^7	$\frac{ft \cdot lb}{SEC}$	1.35582×10^7
15	Intensity of stress	—	1 -1 -2	f/A	$Dyne/cm^2$	$\frac{Dyne\text{-}5}{meter^2}$	10	$\frac{Dyne\ 1/2}{Quad^2}$	10^{-20}	$\frac{Dyne\text{-}1}{cm^2}$	10^7	lb/sq ft	478.80
16	Modulus of elasticity	E	1 -1 -2	$p \cdot \frac{\Delta L}{L}$	$Dyne/cm^2$	$\frac{Dyne\ 5}{meter^2}$	10	$\frac{Dyne \cdot 1/2}{Quad.^2}$	10^{-20}	$\frac{Dyne\text{-}1}{cm^2}$	10^7	lb/sq ft	478.80
17	Elastance (stiffness)	S	1 0 -2	f/L	Dyne/cm	$\frac{Dyne\text{-}5}{meter}$	10^3	$\frac{Dyne\ 1/2}{Quad.}$	10^{-11}	$\frac{Dyne\text{-}1}{cm}$	10^7	lb/ft	14594
18	Compliance	C	-1 0 2	1/S	cm/dyne	$\frac{meter}{Dyne\text{-}5}$	10^{-3}	$\frac{Quadrant}{Dyne\ 1/2}$	10^{11}	$\frac{cm}{Dyne\text{-}1}$	10^{-7}	ft/lb	6.8515×10^{-5}
19	Resilience	—	1 2 -2	$\frac{W \text{ of elasticity}}{}$	Dyne·cm	Joule	10^7	Joule	10^7	Joule	10^7	ft·lb	1.35582×10^7
20	Viscosity	ν	1 -1 -1	$\frac{f \cdot L}{A} / v$	$\frac{Dyne \cdot sec}{cm^2}$	$\frac{Dyne\text{-}5 \cdot sec}{meter^2}$	10	$\frac{Dyne\ 1/2 \cdot sec}{Quad^2}$	10^{-20}	$\frac{Dyne\ 1 \cdot sec}{cm^2}$	10^7	$\frac{lb \cdot sec}{ft^2}$	478.80
			Dimensions $Q = M^a L^b T^c \theta^d$ a b c d										
	ROTATIONAL MECHANICS												
21	Angle	θ	0 0 0 1	Fundamental	radian	radian	1	radian	1	radian	1	radian	1
22	Angular velocity	ω	0 0 -1 1	$d\theta/dT$	rad/sec	rad/sec	1	rad/sec	1	rad/sec	1	rad/sec	1
23	Angular acceleration	α	0 0 -2 1	$d\omega/dT$	rad/sec^2	rad/sec^2	1	rad/sec^2	1	rad/sec^2	1	rad/sec^2	1
24	Torque	q	1 2 -2 -1	W/θ	$\frac{dyne \cdot cm}{radian}$	$\frac{Joule}{radian}$	10^7	$\frac{Joule}{radian}$	10^7	$\frac{Joule}{radian}$	10^7	$\frac{ft \cdot lb}{radian}$	1.35582×10^7
25	Moment of inertia	J	1 2 0 -2	$2W/\omega^2$	$\frac{gm\ cm^2}{rad^2}$	$\frac{Kg \cdot m^2}{rad^2}$	10^7	—	10^7	$\frac{gm\ 1\ cm^2}{radian^2}$	10^7	$\frac{slug \cdot ft^2}{radian}$	1.35582×10^7
26	Torsional rigidity	—	1 2 -2 -2	q/θ	$\frac{Dyne\ cm}{Radian^2}$	$\frac{Joule}{Radian^2}$	10^7	$\frac{Joule}{rad^2}$	10^7	$\frac{Joule}{rad^2}$	10^7	$\frac{ft\ lb}{rad^2}$	1.35582×10^7
27	Arc	—	0 1 0 1	θ radius	cm radian	$\frac{Meter \cdot}{radian}$	10^2	Quad·rad.	10^9	cm·radian	1	ft·radian	30.4801

	QUANTITY	SYMBOL	DIMENSION Q=M^a L^b T^c θ^d a b c d	DEFINITION	C G S NAME	MKS NAME	MKS C.G.S. UNITS IN ONE UNIT	GRAM-CALORIE NAME	GRAM-CALORIE C.G.S. UNITS IN ONE UNIT
	HEAT								
28	Quantity of heat	H	1 2 -2 0	Energy	Erg	Joule	10^7	Gm.calorie	4.186×10^7
29	Temperature	θ	0 0 0 1	Fundamental	Degree C	Degree C	1	Degree C	1
30	Thermal capacity	C	1 2 -2 -1	H/θ	Erg / Degree	Joule / Degree	10^7	Gm.calorie / Degree	4.186×10^7
31	Thermal conductivity	K	1 1 -3 -1	H/AE/G	Erg / cm.sec.deg.	Joule / m.sec.deg.	10^5	Cal. / cm.sec.deg.	4.186×10^7
32	Entropy	S	1 2 -2 -1	H/θ	Erg / Degree	Joule / Degree	10^7	Calorie / Degree	4.186×10^7
33	Temp. gradient	G	0 -1 0 1	θ/L	Degree / Cm.	Degree / Meter	10^{-2}	Degree / Cm.	1
	LIGHT		DIMENSION Q: M^a L^b T^c θ^d a b c d						
34	Visibility	v	0 0 0 1	Fundamental	Lumen / Erg/sec	Lumen / Watt	10^{-7}		
35	Luminous flux	F	1 2 -3 1	P × v	Lumen	Lumen	1		
36	Luminosity	L	1 0 -3 1	F/A	Phot	Lux	10^{-4}		
37	Illumination	E	1 0 -3 1	F/A	Phot	Lux	10^{-4}		
38	Luminous intensity	I	1 2 -3 1	4πF	Candle	Candle	1		
39	Focal power	—	0 -1 0 0	1/Focal Length	Cm^{-1}	Diopter	10^{-2}		
	SOUND		DIMENSION Q: M^a L^b T^c θ^d a b c d						
40	Sound energy flux	J	1 2 -3 0	Power	Erg / Sec	Watt	10^7		
41	Sound energy density	E	1 -1 -2 0	v²/v	Erg / Cm^3	Joule / $meter^3$	10		
42	Sound intensity	I	1 0 -3 0	J/A	Erg / Sec. · Cm^2	Watt / $meter^2$	10^3		
43	Audibility	a	0 0 0 1	Fundamental	—	—	10^{-3}		
44	Loudness	L	1 0 -3 1	aI	—	—	1		
45	Acoustic impedance	Z_A	1 -4 -1 0	Pressure / Vol. velocity	"cgs acoustic ohm"	"mks acoustic ohm"	10^{-5}		

the units of current, potential difference, power, charge, work, capacitance, and inductance respectively. Three of these systems are tabulated in Table I, namely those of Maxwell, Dellinger and Bennett, and Giorgi.[9] The notes immediately preceding the table indicate the basis of each of these systems.

The "International" system of units is not absolute, i.e., it is not based on fundamental units of mass, length, and time. It was established to fill the need for more precise standards of electrical quantities than could be determined from absolute measurements. Its units are defined in terms of current, resistance, length, and time. However, because of the great advantages to be obtained from the use of absolute units for all measurements and calculations, and because of the recent increase in the precision with which absolute measurements of electrical quantities can be made, the consensus now is to discard the International System in favor of some one of the practical absolute systems of units. Since the International System has never been used as a complete system, and is soon to be superseded anyway, it has not been included in the table of units. However, the dimensions of the electrical quantities in terms of the fundamental quantities of the Inter-

TABLE III.

Constants of Free Space.

System of Units	μ_0		ϵ_0	
c.g.s. electromagnetic	$1 = 1$		$1/c^2 = 1.113 \times 10^{-21}$	
c.g.s. electromagnetic, rationalized	1	1	$1/c^2 = 1.113 \times 10^{-21}$	
c.g.s. electromagnetic, subrationalized	4π	12.57	$1/4\pi c^2$	8.854×10^{-23}
c.g.s. electrostatic	$1/c^2$	1.113×10^{-21}	1	1
c.g.s. electrostatic, rationalized	$1/c^2$	1.113×10^{-21}	1	
c.g.s. electrostatic, subrationalized	$4\pi/c^2$	1.398×10^{-20}	$1/4\pi$	.07958
Gaussian	1	1	1	1
Heaviside-Lorentz (Gaussian, rationalized)	1	1	1	1
m.k.s. unrationalized	10^{-7}	10^{-7}	$10^{11}/c^2$	1.113×10^{-10}
m.k.s. subrationalized	$4\pi 10^{-7}$	1.257×10^{-6}	$10^{11}/4\pi c^2$	8.854×10^{-12}
c.g.s.s. unrationalized	10^{-9}	10^{-9}	$10^{9}/c^2$	1.113×10^{-22}
c.g.s.s. subrationalized	$4\pi 10^{-9}$	1.257×10^{-7}	$10^{9}/4\pi c^2$	8.854×10^{-15}
q.e.s. unrationalized	1	1	$10^{18}/c^2$	1.113×10^{-3}
q.e.s. subrationalized	4π	12.57	$10^{18}/4\pi c^2$	8.854×10^{-5}

$c = 2.99796 \pm .00004 \times 10^{10}$ in all the above definitions.

[9] For a discussion of this system, and for a bibliography of material on the electrical units, see A. E. Kennelly "I. E. C. Adopts mks system of Units," Elec. Engr. Vol. 54, No. 12, p. 1373, December, 1935.

national System, namely current, resistance, length, and time, have been included because of their relative simplicity and their value in dimensional analysis when only electrical quantities are involved.

Table I presents a rather complete summary of the various systems of electrical units now in use, and of their interrelations. In Table II these systems are extended to include non-electrical quantities, since, for greatest convenience, units of all quantities used in any calculation should be available in one self-consistent system. Table III gives the sizes of the various units of permittivity and permeability of free space, as an aid in comparing the various systems. The following notes on the tables explain their nature and use.

Notes on Table I.

Systems of Units Listed.

c.g.s. electromagnetic:

Fundamental units: centimeter, gram, second, and permeability of free space.

c.g.s. electrostatic:

Fundamental units: centimeter, gram, second, and permittivity of free space.

Rationalized and subrationalized forms of the above two systems.

Gaussian:

This is a mixed system, using electrostatic units for certain quantities and electromagnetic units for others. The letter "G" in column 5 or 11 indicates which kind of unit is used for any particular quantity.

Heaviside-Lorentz:

This is the rationalized form of the mixed Gaussian system. The letter "H" in column 6 or 13 indicates which kind of unit is used for any particular quantity.

Quadrant, gram-eleventh, second (qes) of Maxwell:

Fundamental units: quadrant of the earth's circumference (10^9 cm.), gram-eleventh (10^{-11} gm.), second, and permeability of free space. This is a "practical" system. A "practical" system is defined as one in which the units for current, potential, and power are the ampere, volt, and watt, respectively. (Tabulated in subrationalized form.)

Centimeter, gram-seven, second (c.g.s.s) of Dellinger, Bennett, and others:

This is a "practical" system. Fundamental units (Bennett), centimeter, gram-seven (10^7 gm.), second, and a unit of permittivity such that ϵ of free space in equation (15–1) is

$$\frac{1}{8.9892 \times 10^{11}}$$

Other writers have suggested other fundamental units for this system.

Meter, kilogram, second (m.k.s.) system of Giorgi.

This also is a "practical" system. Fundamental units: meter, kilogram, second, and $10^7 \times$ the permeability of free space (tentative).

Subrationalized form of m.k.s. system.

Names of Quantities.

If no name is given, specify the system and quantity thus:

x c.g.s. electrostatic units of permeability,
y Gaussian units of electric flux.

Note that no names are given for any of the rationalized electrostatic and electromagnetic quantities.

No distinction is made between permittivity and dielectric constant. The terms displacement and electric flux density are used synonymously, and the term polarization applied to the quantity (electric moment per unit volume) in a dielectric.

Symbols.

The symbols follow the generally accepted standards at present. A. I. E. E. specifications are followed when available. Note the duplication of ρ for charge density and resistivity. Context will in general indicate unambiguously which is meant.

Dimensions.

The fundamental quantities in terms of which dimensions are expressed are as follows:

System	*Fundamental Quantities*
1. electromagnetic	mass, length, time, permeability
2. electrostatic	mass, length, time, permittivity
3. "international"	resistance, current, length, time

The third set of dimensions is given because of its simplicity and consequent usefulness in electrical problems.

Defining Equations.

The defining equations indicate the relations among the units of the various quantities in any unrationalized system of units, and furthermore indicate the choice of order of definition in the so-called electrostatic and electromagnetic systems of units.

The table gives the size of the unit for any quantity in each system in terms of the size of the corresponding c.g.s. electromagnetic unit. In addition the relative size of the m.k.s. and electrostatic units are tabulated. "c," in every case, is a dimensionless numerical constant equal in magnitude to the velocity of light in the c.g.s. system, i.e.,

$$2.99796 \pm .00004 \times 10^{10},$$

or approximately

$$3 \times 10^{10}.$$

The relative size of units is specified by stating the number of c.g.s. electromagnetic units which equal 1 unit of the system in question. As an example in which there can be no possible misunderstanding, consider the conversion of length from c.g.s. to m.k.s. units. Under the m.k.s. column (Table II) is found the statement that there are 100 c.g.s. units in 1 m.k.s. unit of length, i.e., that

there are 100 centimeters in 1 meter. If a length has been measured in the c.g.s. system and we want to find its size in the m.k.s. system, we divide by this number (100). If it has been measured in the m.k.s. system and we want its size in the c.g.s. system we multiply by 100.

Notes on Table II.

Table II extends the systems of electrical units to mechanics, heat, light, and sound, thus furnishing complete self-consistent systems of units for practically all physical quantities. Both the c.g.s. electrostatic and c.g.s. electromagnetic systems are consistent with the c.g.s. system for non-electrical quantities. Rationalization in the electrical systems does not affect the mechanical quantities in any way.

Mechanical quantities are listed in the c.g.s., m.k.s., c.g.s.s., and q.e.s. systems, and in additional in the system based on the foot, slug, and second. Thermal quantities are listed in the c.g.s. and m.k.s. systems, and in the system that makes the unit of energy the gram-calorie. Light quantities are listed in the c.g.s. and m.k.s. systems only.

Angle is listed as a fundamental quantity in rotational systems, temperature in thermal systems, visibility in light systems and audibility in acoustical systems. Internationally accepted standards of the first three of these quantities exist.

EXPLOSIVE CHARACTERISTICS OF CERTAIN METALLIC PICRATES.[1]

BY

J. D. HOPPER.[2]

The explosive characteristics of the metallic salts of picric acid are of interest in the technology of explosives chiefly because of the ease with which picric acid combines with many metals and basic compounds to form picrates, some of which are capable of direct detonation when subjected to heat or shock. Although this property of the picrates was known and put to practical use for some time before picric acid was used as an explosive, considerable diversity of opinion still exists in regard to the relative sensitivity of these salts as compared with standard explosives, and the published data on their explosive characteristics are far from complete.

In 1901 Dupré [3] listed several of the metallic picrates in the order of the violence of the explosion obtained when heated to the exploding point and reported experiments indicating that picrates of calcium, lead, and zinc, formed *in situ* were capable of initiating explosion in molten picric acid. In 1906 Will [4] compared a few of the more common picrates with other explosives by sensitivity to impact tests; and two years later Silberrad and Phillips [5] summarized the chemical properties of a large number of the picrates and reported the explosion temperatures of the anhydrous forms.

Kast,[6] in 1911, however, appears to have been the first to correlate the chemical and explosive properties of these salts and to point out the effect of varying amounts of water of crystallization on the sensitivity to impact. Kast found that picrates which had been freed of whatever water of

[1] Published by permission of the Chief of Ordnance, U. S. War Department.

[2] Assistant Chemist, Picatinny Arsenal, Ordnance Department.

[3] A. Dupré, *Mém. poudres*, **11**, 92 (1901).

[4] W. Will, *Z. ges. Schiess-Sprengstoffw.*, **1**, 209 (1906).

[5] Silberrad and Phillips, *J. C. S.*, **93**, 474 (1908).

[6] H. Kast, *Z. ges. Schiess-Sprengstoffw.*, **6**, 7, 31, 67 (1911).

crystallization could be removed by drying at 100° C. were much more sensitive than the same salts dried in a vacuum at ordinary room temperatures. Taking into account the water of crystallization, he concluded that the salts of picric acid, with the exception of ammonium and basic aluminum picrates, are more sensitive than picric acid itself; the heavy metal salts in the order of lead, iron, copper, and silver being most sensitive, followed by the alkaline-earth and then the alkali salts, but that even the most sensitive, anhydrous lead picrate, is not so sensitive as guncotton or dynamite.

Will,[4] however, placed lead, iron, and copper picrates in the class with mercury fulminate and nitroglycerin, these picrates being only slightly less sensitive according to his tests; while zinc, sodium, and ammonium picrates he classed with the relatively insensitive aromatic nitro-compounds of the type of trinitrotoluene, the alkaline picrates being judged somewhat less sensitive than picric acid. The samples tested by Will had been previously dried at 40° C.

In view of the differences of opinion expressed in the literature concerning the relative sensitivity of some of the picrates and the failure of Will [4] and others to establish the compositions with respect to degree of hydration of the salts tested, it was considered desirable to prepare certain of these salts and to subject them to standard sensitivity tests in order to obtain definite data for comparison with other explosives. The study included the normal picrates of sodium, copper, cadmium, zinc, aluminum, nickel, chromium, ferrous and ferric iron, and the sodium salt of dinitrophenol, and covered both the anhydrous and hydrated forms.

In general, the salts were prepared as crystalline hydrates from aqueous solution by the methods outlined by Silberrad and Phillips [5] and Kast,[6] and were dehydrated by being heated at temperatures of 80° to 150° C., depending upon the ease with which the water of crystallization could be driven off to obtain the degree of hydration desired. Special precautions were taken in the preparation of ferrous, ferric, and chromium picrates to avoid decomposition, the temperature and volume of the solutions being maintained at minimum values. The violet form of chromium sulfate was used in the double decomposition reaction with barium picrate, since

the sulfate ion of the green form is not completely precipitated by barium compounds.

METHODS OF TESTING.

The salts were identified by their metallic contents, which were determined by standard laboratory methods. The organic radical was removed where necessary by ashing with nitric and sulfuric acids. The water of crystallization was determined as the loss in weight to constant weight at the indicated temperatures.

The explosion temperature was determined as the temperature necessary to cause ignition or explosion in exactly five seconds when a thin-walled copper shell containing a few milligrams of the explosive was dipped into a molten metal bath to a constant depth. The method is that described by Weber.[7] A thermocouple was used to measure the bath temperature and readings were taken at five-degree intervals.

The sensitivity to percussion of the various salts was determined by means of the drop test machine described by Deck.[8] In this test a few milligrams of the explosive is pressed by hand, by means of a wooden spatula, into a hardened tool steel die cup, 0.04 inch deep, and confined by a soft brass cover; the loaded cup is then placed on an anvil between two upright guide rods and a two-kilogram weight is allowed to fall from a known height on a small hardened steel vented and slotted plug placed in the center of the brass cover. The vent extends from one face to the other of the cylindrical vented plug, while the slot is diametrically across one face. The slotted face is placed down on the brass cover. Both the vented plugs and the hardened steel die cups are adjusted by heat treating until they give the accepted drop test values of 14 and 8 inches with pure samples of TNT and tetryl respectively. The above procedure is repeated, the weight being dropped from various heights, until the minimum height at which at least one detonation or ignition is obtained in ten tests is found. This height is a measure of the relative sensitivity to impact of the explosive.

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[7] Bull. U. S. Bur. Standards, **9**, 119 (1913).

[8] H. S. Deck, Army Ordnance, **7**, 34 (1926).

PROPERTIES.

The results of chemical and explosive tests of the various hydrated and anhydrous salts studied are listed in Table I. The drop test values obtained show very definitely, as reported by Kast,[6] that the sensitiveness of the metallic picrates and also of sodium dinitrophenate depends largely upon the amounts of water of crystallization contained in the crystals, the more highly hydrated forms being less sensitive to percussion than the lower hydrates, and the anhydrous forms more sensitive. Heating at 80° to 100° C. expels the bulk of the water of crystallization from the higher hydrates and converts them to lower hydrates, but long heating at abnormally high drying temperatures of 130° to 150° C. is necessary in most cases to drive off all the water of crystallization and thus produce the most sensitive forms. At room temperatures dehydrated forms of the metallic picrates and sodium dinitrophenate absorb water from the air rapidly and tend to become less sensitive.

The hydrated salts, as prepared by crystallization from water and air-drying at room temperatures, are all less sensitive to percussion than any of the standard military high explosives except ammonium picrate. The drop test value of sodium picrate monohydrate and of ammonium picrate is 17 inches; while that of sodium dinitrophenate monohydrate is 16 inches. The value of either TNT or picric acid in this test is 14 inches. Some of these salts, notably the aluminum and heavy metal picrates with several molecules of water of crystallization, barely burned in the test, while others exploded only mildly.

In their more sensitive forms, as prepared by dehydrating at elevated temperatures, the picrates of copper, zinc, cadmium, nickel, chromium, and ferric iron are more sensitive than picric acid; while the picrates of sodium and aluminum and sodium dinitrophenate are less sensitive than picric acid. Ferrous picrate has about the same order of sensitivity as the free acid.

While anhydrous copper, zinc, and cadmium picrates are somewhat more sensitive, having a drop test value of 12 inches, than TNT, they are not nearly so sensitive to percussion as ferric, chromium, and nickel picrates, which when dried at

TABLE I.

Chemical and Explosive Properties of Salts of Picric Acid and Dinitrophenol.

Kind of Explosive	Water of Crystallization	Drying Temperature	Min. Hgt. of Fall of 2-kg. Wgt. to cause Detonation (inches)	Explosion Temperature	Analytical Data			
					% Metal Content		% Water Content	
					Found	Calculated	Found	Calculated
Mercury Fulminate			2	210° C.				
Tetryl			8	260				
TNT			14	470				
Picric Acid			14	320				
Ammonium Picrate	anhyd.		17	320				
Sodium Picrate	1 H_2O	50° C.	17	360	8.52	8.55	6.69	6.70
	anhyd.	150°	15					
Sodium Dinitrophenate	1 H_2O	100°	16	370	10.17	10.27	8.06	8.04
	anhyd.	150°	15					
Copper Picrate	3 H_2O	25°	19	300	11.05	11.08	9.53	9.43
	anhyd.	150°	12		12.10	12.23		
Zinc Picrate	6 H_2O	25°	34	310	10.52	10.38	17.17	17.17
	anhyd.	150°	12					
Cadmium Picrate	8 H_2O	25°	35	340	15.77	15.77	20.08	20.22
	anhyd.	150°	12					
Nickel Picrate	6 H_2O	25°	26	390	9.41	9.42	17.09	17.35
		100°	9					
	anhyd.	150°	4					

TABLE I.—*Continued.*

Kind of Explosive	Water of Crystallization	Drying Temperature	Min. Hgt. of Fall of 2-kg. Wgt. to cause Detonation (inches)	Explosion Temperature	Analytical Data			
					% Metal Content		% Water Content	
					Found	Calculated	Found	Calculated
Aluminum Picrate	10 H_2O	25°	36	360° C.	3.08	3.03	16.27[a]	16.17[b]
	2 H_2O	80°	16				16.83[c]	
		100°	16				Fuses above 100° C.	
Chromium Picrate	13 H_2O	25°	36	330	5.52	5.36	21.26[a]	
		80°	10				22.19[c]	22.28[d]
	1 H_2O	100°	8					
Ferrous Picrate	8 H_2O	25°	36	310	8.61	8.51	18.54[e]	21.96
	Dried over H_2SO_4 in Vacuum Desiccator		15					
		100° C.	14				19.20[c]	
Ferric Picrate	X H_2O	25°	36	295	6.96*	7.55[f]	18.55[a]	
		80°	8				20.86[c]	
		100°	7				23.62[g]	
		150°	6					

[a] Loss at 80° C.
[b] Loss of 8 H_2O.
[c] Loss at 100° C.
[d] Loss of 12 H_2O.
[e] Loss over H_2SO_4.
[f] For anhydrous normal ferric picrate.
[g] Loss at 150° C.
* The iron content of the ferric picrate indicates that a small amount of basic iron is present; as the material is entirely soluble in acetone, the presence of a small amount of a basic iron picrate is indicated.

100° C. can be classed in order of sensitivity with recrystallized tetryl. The ultimate sensitivity of ferric and nickel picrates, however, obtained by prolonged heating at 150° C., places them in the range of sensitivity intermediate between tetryl and the very sensitive primary initiator mercury fulminate, anhydrous nickel picrate being especially sensitive and violent when struck.

The temperatures at which the hydrated salts exploded or burned when heated for five seconds range from 295° C. for ferric picrate to 390° C. for nickel picrate. The explosion of cadmium picrate was particularly violent, while that of aluminum was scarcely more than a deflagration. The explosion temperature of picric acid is 320° C.

In general, a comparison of the sensitivity data obtained in the present tests with those of Will [4] and Kast [6] shows that the order of sensitivity indicated by the data now presented is in fairly good agreement with that indicated by those of Kast obtained by the impact test of the explosives alone, and quite different in several respects from that indicated by Kast's results obtained by impact tests of the explosives mixed with ground glass; while the data recorded by Will for materials of uncertain composition show very little agreement in order of sensitivity and marked disagreement in degree of sensitivity.

SUMMARY.

The relative sensitivity of the metallic picrates and of sodium dinitrophenate depends largely upon the amounts of water of crystallization present. The highly hydrated forms are very insensitive, the lower hydrates are in general more sensitive, and the anhydrous forms most sensitive.

The anhydrous salts of picric acid, with the exception of sodium, ammonium, aluminum, and ferrous picrates, are more sensitive to percussion than picric acid itself. Anhydrous copper, zinc, and cadmium picrates are only slightly more sensitive; while anhydrous nickel picrate is especially sensitive, lying in the sensitivity range between mercury fulminate and tetryl.

The sensitive anhydrous forms are obtained with difficulty by long heating at temperatures above 100° C.

Glaze-Raise, a New Concrete Building Material.—(*Compressed Air Magazine*, Vol. 42, No. 9.) Concrete with a glazed, raised surface is the newest development in building materials. It is a patented product manufactured on a commercial scale in London, England. The product is made by a process that gives the concrete a tool-raised finish with a luster equal to that of plate glass or the best grade of tiling. A mat or a sand-blast finish, or a combination of all three can also be produced, as well as an unlimited range of designs and color effects both plain and variegated. This makes it possible to reproduce marble. Machinery used for the ordinary concrete making is all that is necessary for making the new material. Tests have proved Glaze-Raise to be well nigh indestructible. These included exposing specimens to extremely low and high temperatures to determine the durability and quality of the finish.

R. H. O.

Use of Electricity to Treat Disease Fulfills Half-Century-Old Prophecy.—(*Electrical Engineering*, Vol. 56, No. 10.) The scientist who made this prophecy is still alive. He is 86 year old Professor A. D'Arsonval of Paris. He recalled his early statement (1882) in a message to the first International Conference on Fever Therapy recently held in New York. Professor D'Arsonval is honorary president of the French committee of the conference.

R. H. O.

No Summer Layoffs Now in Air Conditioned Mine.—(*Refrigerating Engineering*, Vol. 34, No. 4.) High temperatures and high moisture content of the air in the Magma Copper Mine at Superior, Arizona caused summer layoffs for the workmen amounting to about four weeks each year. The temperatures were caused by heat which rises from the lower levels of the earth, and conditions became worse as the mine grew deeper. The humidity was caused by evaporation of the larger amount of water found underground. To correct these conditions a Carrier air conditioning system, similar to that in the Deep Gold mines in South Africa, was installed. After the first few days of operation, spokesmen for the miners requested permission to resume work. This is the first underground air conditioning in the United States.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

INDUSTRIAL USES FOR SILVER.

In Technical News Bulletin 244 (August, 1937) there appeared an outline of the research program sponsored by a group of leading American silver producers to develop new industrial uses for silver.

Since appointment of the last of the fifteen research fellowships about the first of June, 1937, there has been an active study made along the various lines mapped out in the earlier report on this project. Definite progress has been made in each field studied, and in several instances indications are that the particular researches will, when completed, be of considerable interest to industry.

At one institution a Silver Research Project Fellow has been investigating the antifriction properties of silver and silver-rich alloys. Amsler wear tests evaluate the load which produces a given coefficient of friction and give information regarding the tendency of the alloy to gall and score a steel journal. The effect on the antifriction qualities of a great many elements added to pure silver has been determined. Pure silver has been found exceptionally qualified for use as a bearing material, most alloy additions producing inferior results. The data being obtained are of special interest because steel-backed bearings lined with nearly pure silver have come into commercial use within the year, being standard equipment on certain aviation engines. Because of the resistance silver offers against galling and scoring it is being considered for shims and metallic packing. The latter application takes advantage, also, of the resistance of silver to heat and corrosion.

Two research investigators studying the electrodeposition of silver and of silver alloys have developed methods for obtaining adherent deposits on steel and for co-deposition of a number of elements with silver. The development of fur-

* Communicated by the Director.

ther improvements in electroplating technique is expected to extend materially the usefulness of silverplating in the chemical and other industries.

The study of silver slip-rings and silver-graphite brushes for rotating electrical contacts has demonstrated marked advantages for these materials over carbon or copper-graphite brushes and copper slip rings or commutators. Contact voltage drop is very much less, operation follows the Ohm's Law relationship closely, and much higher current densities can be tolerated. Furthermore, there is much less polarity effect when using the silver contacting surface. Manufacturers of electrical equipment have already taken cognizance of these test results which may lead to improved design in certain electrical equipment.

Very satisfactory results have been obtained with silver as a catalyst in the oxidation of ethyl alcohol, operating at conditions varying considerably from commercial practice.

Data are being obtained on heat transfer through silver. The use of a commercial 50-gallon vessel of pure silver has reduced a batch operation cycle from 48 hours when carried out in glass-lined equipment to only 4 hours, with an increase in thermal economy and with less degradation of the product. Scientific data on such performances are, however, lacking, and it is believed that this research will contribute heat transfer data of use to the mechanical and chemical engineer.

The ability of silver salts to act as potent fungicides has been demonstrated by a Silver Research Project Fellow and the agricultural possibilities are being studied in some detail. This research also appears very promising in connection with water sterilization, particularly for fish hatcheries.

A thorough study of the medical literature on argyria, or alleged silver-poisoning, has been made as a preliminary step by the Research Fellow investigating the toxicological properties of silver. Very little reliable information on this subject is available, and further study is needed to evaluate the extent to which this may be a problem of practical interest to other than the medical profession. Another research worker in the medical field is studying the "mechanism" of the action of silver on bacteria by determining what particular

chemical group of the organism reacts with silver or the silver ion.

The permeability of hot silver to oxygen has been considered as a means of fractionating air. Calculations show interesting possibilities, and experimental work is being undertaken to verify the calculations and the practicability of using this principle in enriching blast furnace air, for example. The solubility of oxygen in molten silver offers another possible line of attack and this also is being considered.

The effect of additions of silver in small amounts (up to about five per cent.) to the engineering alloys is being studied on a comprehensive scale through coöperation of five men working at three different institutions. These same research workers are also noting the effect of small additions of other metals to pure silver. In general, the response to various annealing and hardening treatments and to corrosion is being studied. It is expected that data will also be obtained on castability, mechanical properties, electrical conductivity, and other properties likely to be of special interest. Almost two hundred alloys have been prepared for this work.

Special attention is being devoted to the lead-silver solders containing from about two to six per cent. of silver, with and without other additions, as competitors with the lead-tin solders and as intermediate temperature solders. Long time creep test data are being obtained on soldered joints made with such alloys, at both room and elevated temperatures.

Another investigation sponsored by this Project has to do with the effect of silver additions to storage battery grids.

Technical data are being gathered on all silver alloy systems, the patent literature dealing with silver, and the use of silver in the chemical industry.

The Senior Research Associate, A. J. Dornblatt, of the National Bureau of Standards, has recently visited some sixty companies and research laboratories to acquaint them with the objectives of the various researches and the results being obtained on this Project, and to solicit suggestions and data from their staffs. Parties interested in any phase of the American Silver Producers' Research Project are invited to correspond with Mr. Dornblatt for further details.

α-d-β-MANNOHEPTOSE.

The preparation by Horace S. Isbell of a new sugar, α-d-β-mannoheptose, will be described in an article to appear in the *Journal of Research* for February. The sugar crystallizes as a monohydrate which melts at 83° C., gives an initial specific rotation of + 45.7, and exhibits a complex mutarotation which can be represented by the following equation:

$$(\alpha)_D^{20} = 14.5 + 8.3 \times 10^{-.0141t} + 22.9 \times 10^{-.0916t}.$$

The sugar was obtained by the reduction of the gamma lactone of d-β-mannoheptonic acid and was separated in the form of prismatic crystals which melted at 130° C. and which gave a specific rotation $(\alpha)_D^{20} = -35.7$.

The new sugar is structurally related to α-d-talose and exhibits similar properties. Oxidation measurements with bromine water show that α-d-β-mannoheptose is oxidized at a rate comparable to that found for the oxidation of α-d-talose and that aqueous solutions of the sugar contain substantial quantities of more rapidly oxidizable modifications. The parallelism between the properties of α-d-talose, α-d-α-guloheptose, and α-d-β-mannoheptose is evidence that the configuration of the five carbon atoms comprising the pyranose ring determines in large measure the composition of the equilibrium solutions of the sugar.

EXHIBIT OF RARE SUGARS.

At the meeting of the American Association for the Advancement of Science held in Indianapolis December 27–30, inclusive, the Bureau's polarimetry section exhibited a collection of rare sugars which is unique in that it includes all of the pentose, hexose, and heptose aldose sugars of the *d* configurational series which are known products at the present time. These sugars have been prepared by various members of the staff without seed crystals from other sources. The group comprises four pentoses, eight hexoses, and eight heptoses, all of which are in the crystalline state with the exception of *d*-idose which has never been crystallized. The following sugars in the collection were crystallized for the first time at the Bureau:

d-Allose,
d-β-Glucoheptose,
d-α-Guloheptose,
d-Gulose $CaCl_2$,
d-β-Mannoheptose.

WATER TOLERANCES OF MIXTURES OF GASOLINE WITH ETHYL ALCOHOL.

During recent years the interest in the use of mixtures of gasoline with ethyl alcohol as engine fuels has increased because of the desire to provide an outlet for agricultural products which can be converted into ethyl alcohol. One of the major difficulties in connection with the use of this type of fuel is that only a very small amount of water may cause the mixture to separate into two layers.

The temperature at which separation occurs depends upon the particular gasoline and upon the proportions of gasoline, ethyl alcohol and water in the mixture. In a previous investigation, data were obtained on the separation temperatures of mixtures in various proportions, of 23 different gasolines with ethyl alcohol containing various percentages of water. From these data, it is easily possible to obtain the water tolerances of any of these gasolines at any given temperature within the range investigated. Analysis of the water tolerance values indicated certain similarities in the trend of water tolerance with composition of the mixtures when comparing the results with different gasolines. This suggested the possibility of deriving a general empirical equation for the water tolerance of mixtures of gasoline and ethyl alcohol and of assigning to any gasoline a characteristic constant which would be indicative of the water tolerance of any mixtures of this gasoline with ethyl alcohol.

The derivation of this empirical equation and the characteristic constants as calculated for each of the 23 gasolines are set forth in RP1059 by Oscar C. Bridgeman and Elizabeth W. Aldrich in the January number of the *Journal of Research*. The difference between the experimentally determined separation temperatures and those calculated from the equation was on the average 1.4° C., and the difference between

observed and computed water tolerances was about 0.005 per cent. of the total mixture.

The equation which has been developed makes possible the calculation of the water tolerances of mixtures of any gasoline with any percentage of ethyl alcohol from measurements of the separation temperatures of a few mixtures of known composition of this gasoline with ethyl alcohol.

PERFORMANCE CHARACTERISTICS OF VENTURI TUBES.

Venturi tubes are used in many airplanes to furnish the suction for operating air-driven gyroscopic instruments. While the operating efficiency of venturi tubes is low as compared to vacuum pumps, their cheapness and mechanical simplicity have furthered their continued use in many installations. The lack of data on the performance and design of venturi tubes used as vacuum pumps has made it desirable to undertake an experimental study of their performance and design characteristics. As part of this study, Harcourt Sontag and Daniel P. Johnson of the Bureau's aeronautic instruments section have determined the performance characteristics of commercially available venturi tubes, and these characteristics are presented in technical note 624 just released by the National Advisory Committee for Aeronautics. The investigation was made with the coöperation and financial support of the above Committee.

Tests were made in a wind tunnel and in flight to determine the performance characteristics of three samples each of two designs of venturi tubes now used in airplanes to operate air-driven gyroscopic instruments. In the tests the variation of the suction developed at the venturi inlet with the air flow, the speed, and air density were measured; also the drag and the effect of pitch and yaw. Rather large variations of the suction, drag, and efficiency were found between individual tubes of the same design. Cylindrical fairing on the external surface of a venturi tube resulted in a reduction of drag and suction at a given air speed but produced no appreciable change in efficiency.

For constant values of the ratio of suction to atmospheric pressure, the air flow is approximately a linear function,

independent of altitude for a double venturi tube, of the product of the indicated air speed and the square root of the ratio of standard air pressure to the atmospheric pressure. Consequently, data obtained at sea level may be used to make approximate predictions of performance at higher altitudes. There is some indication that this may also be done for single venturi tubes.

For a given installation in which an air-driven instrument is connected through tubing with a venturi tube, the volume rate of induced air flow is approximately proportional to the product of indicated air speed and the square root of the ratio of standard to ambient air pressure. The efficiency of such a system at a given altitude is constant.

PASSAGE OF MOISTURE THROUGH WRAPPING MATERIALS.

Some wrapping materials, and other membranes as well, that are practically impermeable to air allow moisture to pass through them readily. Several explanations for this seemingly strange behavior have been advanced. A review of these explanations is given in an article prepared for publication in Food Industries by F. T. Carson of the Bureau's paper section.

The article also discusses the influence of various factors in the testing of membranes for permeability to moisture. The amount of moisture that gets through a membrane depends upon the time it is exposed, and upon its area and thickness. One of the most serious sources of error commonly encountered in testing for permeability to moisture is leakage. The driving pressure is determined by the vapor-pressure difference, or by the difference in the humidity conditions on the two faces of the membrane. The relative humidity, especially on the moist side, is an important factor. The atmospheric pressure, or barometric pressure, also has an influence on the test, especially if different on the two faces of the specimen. The test is affected by the temperature and by the rate of diffusion of water vapor in still air. It may also be influenced by the state of the moisture (whether liquid or vapor) in contact with the membrane.

CONSISTENCY OF EIGHT TYPES OF VITREOUS ENAMEL FRITS AT AND NEAR FIRING TEMPERATURES.

In the firing of a vitreous enamel on metal, it is desirable that the grains should fuse together and flow out smoothly at as low a temperature as possible. The adjustment of batch compositions to achieve acid resistance, high opacity, or other desirable characteristics may increase the temperature required for firing, and it is, therefore, important to correlate the composition of enamels with their consistency at and near firing temperatures. As the first step in such a correlation, W. N. Harrison, R. E. Stephens, and S. N. Shelton have tested eight vitreous enamel frits, representing eight commercial types, in the temperature range 750 to 950° C., using a rotation viscometer. As reported in RP1063 in the January *Journal of Research*, the two first-coat frits behaved as viscous liquids, the shearing stresses at any given temperature being proportional to the rates of shear. Four of the cover-coat enamels behaved as complex liquids, the shearing stress increasing at increasing rates with rates of shear. Two cover-coat frits, containing lead oxide behaved rather erratically.

The change of apparent viscosity with temperature was great in all cases, an increase of as much as one hundred fold being observed for a reduction of 200° C. At a single temperature, 839° C., the highest observed apparent viscosity was 28 times as great as the lowest. Two cover-coat frits, having a 12 fold difference in apparent viscosity at 850° C., had equal apparent viscosities when the temperature difference between these frits was 125° C., comparison being made at equal torque in the apparatus. The highest observed apparent viscosity was 61,000 poises, which was nearly 400 times greater than the smallest observed value of 155 poises.

STRENGTH, WATER ABSORPTION, AND RESISTANCE TO FREEZING AND THAWING OF SAND-LIME BRICK.

The American Society for Testing Materials' current Standard Specification for Sand-Lime Brick was written in 1929. At that time those interested in specifications for building brick were thinking almost wholly in terms of

strength. Strength of brick was regarded not only as a desirable property in itself, but also as a measure of weather resistance. However, studies of clay and shale brick have shown that strength is not a clear-cut measure of weather resistance when a wide range of raw materials such as clays and shales are considered, and that there also exist other measures for this property. Among these are the ratio of cold water absorption to absorption by boiling which serves to grade clay and shale bricks from the standpoint of weather resistance more effectively than either strength grading of water absorption alone.

From the standpoint of emphasis on durability grading, the question asked is, what changes should be made in the sand-lime brick specification? To provide an answer to this question, J. W. McBurney and A. R. Eberle of the Bureau's section on masonry construction have tested samples of sand-lime brick from 11 commercial plants. The data obtained included compressive strength (flatwise), modulus of rupture, water absorption by 24-hour cold immersion and 5-hour boiling, the ratio of these two absorption measures, the rate of absorption by 3-minute partial immersion in water, and the effect of 50 cycles of freezing and thawing measured both by loss in weight and change in compressive strength. Sieve analyses were made of samples of sands which the 11 plants used in making the bricks. The conclusions from these data which will be set forth in detail in RP1065 in the January number of the *Journal of Research* indicate that:

(1) Comparison of compressive strengths of sand-lime brick from plants sampled in 1936 with the results of previous tests on brick from the same plant sampled in 1928 shows an average gain in compressive strength of 37 per cent.

(2) Neither water absorption by 24-hour cold immersion, nor by 5-hour boiling, is related to resistance to freezing and thawing.

(3) The ratio water absorption by 24-hour cold immersion to water absorption by 5-hour boiling is not related to resistance to freezing and thawing.

(4) There does not appear to be a consistent relation between rate of absorption and resistance to freezing and thawing.

(5) A marked increase in compressive strength resulted from 50 cycles of freezing and thawing where the brick possessed originally compressive strengths greater than 6500 lb./in.^{2} or moduli of rupture greater than 800 lb./in.^{2}

(6) Good correlation with resistance to freezing and thawing is given by the compressive strengths.

(7) Correlation between resistance to freezing and thawing and modulus of rupture is excellent.

(8) Complete disintegration occurred only on bricks made from a sand containing clay balls retained on a $\frac{3}{8}$ in. sieve.

(9) Of 120 bricks subjected to 50 cycles of freezing and thawing, a limit of 10 per cent. loss in weight rejected 3 specimens, 3 per cent. loss in weight rejected 11 specimens, 3 per cent. loss in weight and more than 25 per cent. reduction in compressive strength rejected 23 specimens, and a limit of 1.0 per cent. loss in weight and 25 per cent. loss in compressive strength rejected 34 specimens.

(10) Of 43 bricks grading "A" under the current American Society for Testing Materials Specification C73-30 for Sand-Lime Brick, 41 passed and 2 failed when subjected to 50 cycles of freezing with the requirement of not losing more than 1.0 per cent. in weight or more than 25 per cent. in compressive strength. Of 71 bricks grading "B," 45 passed and 26 failed by the same requirement. Of 6 bricks grading "C," all failed. Had the requirement given in the specification under the "Inspection and Rejection" clause, which provides that the bricks "shall be free from . . . balls of clay . . . that would affect their serviceability or strength" been applied, the showing of the "B" grade would have been much better.

Since resistance to freezing and thawing is best correlated with strength, the Bureau's recommendation is to regard the strength classification of the current specification for sand-lime brick as a weathering classification. A tightening of the "Inspection and Rejection" clause is desirable.

THE FRANKLIN INSTITUTE.

ANNUAL MEETING, JANUARY 19, 1938.

The annual meeting of The Franklin Institute was held on the evening of Wednesday, January 19, 1938, at 8:30 o'clock, with Mr. W. Chattin Wetherill, Vice-President, in the chair. The Chairman announced that the minutes of the December meeting had been printed in full in the January issue of the JOURNAL, and if there were no corrections or additions, they would be approved as printed. No objections being offered, the minutes were declared approved.

The next business was the reading of the report of the tellers of the annual election, which indicated that the following gentlemen were duly elected:

President (To serve 1 year)	Philip C. Staples
Vice-Presidents (To serve 1 year)	Walton Forstall
	W. Chattin Wetherill
	S. S. Fels
Treasurer (To serve 1 year)	Benjamin Franklin
Managers (To serve 3 years)	G. H. Benzon, Jr.
	G. H. Clamer
	Clarence L. Jordan
	L. H. Kinnard
	Conrad N. Lauer
	Richard T. Nalle
	Charles Penrose
	Samuel M. Vauclain
(To serve 1 year)	William Fulton Kurtz

The report was adopted and the Chairman declared the gentlemen named elected to the several offices.

The Secretary then presented a statement of the activities of the Institute and the Museum during the past year.[1]

The Chairman then introduced Dr. Harold C. Urey, Professor of Chemistry, Columbia University, who addressed the meeting on "Concentration of Isotopes by Chemical Means."

The speaker described in detail his numerous experiments over a number of years in the field of the separation of hydrogen isotopes. He described in detail the distillation methods and chemical exchange methods using a very efficient fractionation column with considerable success. The advantage of these methods lies in the large amounts of materials which can be produced, though as yet, high concentrations have not been secured. The subject was illustrated by lantern slides of apparatus, tables of results and other pertinent material.

After a brief discussion, the Chairman conveyed the thanks of the meeting to the speaker.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

[1] See next page.

REPORT OF THE SECRETARY AND DIRECTOR OF THE FRANKLIN INSTITUTE.

I am very happy to follow our usual custom and to give to you tonight a brief summary of the activities of The Franklin Institute.

The most important event of course is the dedication of the building, which will take place on May 19, 20 and 21, 1938. During the past year we have been working steadily to insure the success of this very important occasion. You will be interested to know that our President, Mr. Staples, and some other outstanding citizens of Philadelphia have had interviews with the President of the United States and other high government officials, with the result that we have been assured that the President of the United States will come to Philadelphia on May nineteenth to unveil a heroic statue of Benjamin Franklin, which will complete this national memorial which is Philadelphia's tribute to this great American.

We have also received assurance from other officials in Washington that they will be glad to coöperate in every way, both by their presence and by the active participation of their departments, to make this an outstanding event in the field of science and civic achievement.

The membership of The Franklin Institute will be kept informed of the progress we are making through the Institute News. In due course invitations will be sent out which will be received by our members. We hope greatly the programme which has been planned will prove an interesting one to you and that we shall have your fullest coöperation in our efforts to do honor to Benjamin Franklin.

I am sure our members were interested in the new by-laws which appeared in the November issue of the JOURNAL OF THE FRANKLIN INSTITUTE. By the passage of these laws, we were able to clarify many of the regulations with reference to the organization of the Institute.

The Museum of The Franklin Institute has more than justified its existence during the last year. An appeal to our members and the public at large is made by the use of special demonstrations which are here for a limited length of time. Last Spring we were able to bring to Philadelphia the "Transparent Woman," an exhibit which had a tremendous appeal, and brought to the Institute thousands of people. This was but one of the many exceedingly interesting exhibits which have brought the public to our doors. In countless instances nationally-known firms have coöperated to give us exhibits of real educational value, which have made the public eager not only to visit our Museum but to become members of The Franklin Institute. By this coöperation which is welcomed by us and freely given by large corporations, The Franklin Institute is doing a very useful service for industry, for through this medium industry is able to show to the public, through an impartial agent, what it can do.

In connection with our Museum, we have also established various classes which call for coöperation with other groups in Philadelphia. We have, for instance, the Amateur Telescope Makers' classes, Model Railroad Makers' Association, Pennsylvania Model Airplane Association, and a course in Celestial Navigation given in coöperation with Temple University and Drexel Institute.

For the past several years, on the second and fourth Sundays of each month, we have given to the public a series of musicals which gives the history of musical instruments and composers, as well as illustrations from the works of these noted men. In this way, the public has been made acquainted with ancient instruments

and the part which science has played in their development. Due to the enormous amount of interest in Wagnerian Opera, our Music Department has instituted a special course of ten lecture-recitals, given on Monday evenings at eight. They have proved to be well-received and apparently fill a long-felt want.

Up to December 31st, the total attendance was over 1,700,000 from the time the Museum opened in 1934. For the last year the attendance has been increased by 12½ per cent. in our Museum, and 12 per cent. in our Planetarium.

The Franklin Institute now has going throughout the United States an international Poster Show which was shown first in The Franklin Institute under the title "New Poster." It has been shown in most of the important cities of the United States and is still on the road.

An innovation has been the traveling shows which have been sent throughout the east by The Franklin Institute. One is a Chemistry Show and the other an Air Show. They have visited schools, clubs, colleges, and fraternal organizations of every description, and have brought the story of the Museum to people who cannot get to Philadelphia to see the wonderful exhibits displayed in our building. The two shows now on the road have met with brilliant success and will be continued. It is our hope that in the near future we may add others which will prove equally successful. It costs a substantial sum to give one of these scientific demonstrations. Through support from The Carnegie Corporation and friends, we are able to sell the shows to accredited schools for a nominal charge. This will illustrate how the work of the Institute is recognized and assisted.

Special Christmas and Easter programmes in the Planetarium are given and periodically other demonstrations throughout the year are given special attention, in order to emphasize in a pleasing manner the value of this great scientific instrument which has been placed in our Museum.

The oldest, most used, and highly honored functions of The Franklin Institute are the Library and the JOURNAL. We are pleased to report that during the past year, volumes 223 and 224 of the JOURNAL OF THE FRANKLIN INSTITUTE were published. Members who receive this important publication will have noted papers from Drs. Einstein, Millikan, Bancroft, Fernberger and many others. It is a pleasure to report that we have a waiting list of original papers which indicates that our scientists realize that a paper published in the JOURNAL OF THE FRANKLIN INSTITUTE carries additional merit.

The Library is used daily by members of the Institute and their friends. During the past year nearly 8,000 persons were visitors and over 2,000 telephoned for information, and the Library was enriched by gifts of 1,100 volumes and over 1,000 pamphlets and maps.

The Committee on Science and the Arts, which is responsible for the award of our medals, has been functioning as usual during the past year. The result of the work of this Committee is always made public to the members at Medal Day, when the Medalists are present to receive the public recognition of their works, as recommended by the Committee on Science and the Arts.

Two other departments of the Institute which are of paramount importance are explained to the membership in individual meetings. I refer to the Biochemical Research Foundation, the activities of which are reported upon on the third Wednesday in December, and the Bartol Research Foundation of the Institute, upon which its Director makes a report to the members of the Institute on the third Wednesday in April. However, I should like to refer you to the JOURNAL

OF THE FRANKLIN INSTITUTE where these reports are published in detail. You will be interested and perhaps impressed to know the exceedingly interesting and important work which is being done in these two research departments of The Franklin Institute.

This past year, the Committee on Meetings has digressed somewhat from the usual routine in preparing the course of lectures which is presented to the members each year. It has been the aim of this Committee to obtain at least one lecture a month which would contain the "human interest" background in the story of science. To this end, we have brought to the Institute men who have devoted their lives to scientific work. We have been fortunate in having them give us the interesting story which lies behind many famous discoveries.

You are all acquainted with the lecture list for the remainder of the year. We feel that it is of very high calibre and will receive the enthusiastic accord of the members, which has been given to the lectures thus far this year.

After a thorough study, our Membership Department has re-cast the various forms of membership in The Franklin Institute, with gratifying results. We are pleased to announce that a total of 828 new members were elected to The Franklin Institute in the past year.

The Endowment Committee of The Franklin Institute has established during the past year an organization known as "Friends of Franklin," who have made substantial monetary contributions to assist the Institute in meeting the many financial demands upon it.

It is a pleasure to me to be able to report that in the short space of time in which the "Friends of Franklin" have been in existence the interest which has been displayed by all those who have been approached and the friendly responses which have been made have been most gratifying and very heartening to those in charge of the well-being of the Institute.

We have tried to keep our members and the public fully informed of the various activities of The Franklin Institute through our Department of Public Relations. This department each month publishes the Institute News which brings you up-to-date notices regarding the many activities which are carried on for members and the public.

In addition, you will see in the newspapers, in the street cars, in the taxicabs, in your mail, will hear over the radio, and in fact any place where public notices are displayed, some poster or card to remind you of the splendid educational activities which are carried on in The Franklin Institute with the aid of your untiring and devoted coöperation.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 12, 1938.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 12, 1938.

DR. WINTHROP R. WRIGHT *in the Chair.*

The following reports were presented for final action:

No. 3035: Apparatus for Broadcasting Time Signals.

This report recommended the award of Edward Longstreth Medals jointly to Frederick Hellweg, Captain, United States Navy (Retired), and Paul Sollen-

berger, both of Washington, D. C., "In consideration of their invention of a device combining a crystal controlled clock with a stroboscopic reading element and apparatus for emitting radio time signals, whereby the accuracy of these signals has been increased and the labor of preparing for their transmission reduced."

No. 3047) The Standing Committee on the Franklin Medal presented
No. 3048) its report for final action making the following recommendations:

"That the recipients of the two Franklin Medals to be awarded in 1938 be:

"WILLIAM FREDERICK DURAND, of Stanford University, California, 'In recognition of his notable achievement as pioneer in laboratory research and theory of aeronautics, and of his diversified and distinguished contributions to the sciences of hydrodynamics and aerodynamics, particularly to the advancement of the theory and development of aircraft propellers';

"And CHARLES AUGUST KRAUS, of Providence, Rhode Island, 'In recognition of his numerous and fundamental researches in Chemistry and Electrochemistry, particularly, his valuable contributions to the knowledge of reactions in liquid ammonia, of the chemical behavior of metals, and of the properties of electrolytic solutions.'"

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M.. 637 readers made use of the facilities during the twenty-six days of December.

RECENT ADDITIONS.

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Chemical Engineering Catalog. Twenty-second Edition. 1937.

HILLS, FRANKLIN G. The Technical Analysis of Ores and Metallurgical Products. 1937.

Institution of Petroleum Technologists. Petroleum Technology 1935 and 1936. Two volumes. 1936–1937.

KRUMBHAAR, WM. The Chemistry of Synthetic Surface Coatings. 1937.

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American Radio Relay League. Radio Amateur's Handbook. Fifteenth (1938) Edition. 1937.

ESTY, WILLIAM, ROBERT ANDREWS MILLIKAN, AND WYNNE L. MCDOUGAL. Elements of Electricity. A Practical Discussion of the Fundamental Laws and Phenomena of Electricity and their Practical Applications in the Business and Industrial World. 1937.

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Naval Architecture and Navigation.

ARTIÑANO, GERVASIO DE. La Arquitectura Naval Española (en Modera). Bosquejo de sus Condiciones y Rasgos de su Evolución. 1920.

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CLERC, L. P. Photography Theory and Practice; Being an English Edition of "La Technique Photographique". Edited by the late George E. Brown. Second Edition. 1937.

FRAPRIE, FRANK R., AND FRANKLIN I. JORDAN. Photographic Hints and Gadgets. 1937.

POTONNIÉE, GEORGES. The History of the Discovery of Photography. Translated by Edward Epstean. 1936.

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LORENTZ, H. A. Collected Papers. Volume 5. 1937.

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RHINE, J. B. New Frontiers of the Mind. The Story of the Duke Experiments. 1937.

STUART, C. E., AND J. G. PRATT. A Handbook for Testing Extra-Sensory Perception. 1937.

Sanitary Engineering.

London, Metropolitan Water Board. Thirty-third Annual Report for the Year Ended 31st March, 1936.

Scientific Essays.

CHASE, CARL TRUEBLOOD. Frontiers of Science. 1936.

BOOK REVIEWS.

NEW FRONTIERS OF THE MIND, by J. B. Rhine. 275 pages, plates, 14 × 21 cms. New York, Farrar & Rinehart, Inc., 1937. Price $2.50.

Much has been written in recent years on that ability of the mind sometimes termed the "sixth sense." In fact the popularity of the researches along these lines has even penetrated the radio, which is now employed to conduct tests. Present interest in the subject is perhaps based to a large extent on work at Duke University where a number of competent people about seven years ago decided to investigate in the light of modern scientific knowledge. This book is a story of that investigation and its author has been intimately connected with the work since its inception.

Written in the form of a narrative it describes researches with the express purpose of determining whether anything enters the mind by a route other than the recognized senses. Many of us have experienced unexplained instances of monition, "streaks of luck," "mind reading," telepathy, etc., which at the time aroused curiosity, but has been either forgotten or assigned to the category of superstition, delusion, or mere chance. The investigators at Duke at the beginning of the experiments recognized this and they called the powers of the mind which could learn things without the use of ordinary sensory avenues "extra-sensory perception" or ESP for short. They established tests in which 25 cards were used, divided equally into five parts, each part containing cards of a different

printed design such as a circle, cross, rectangle, star, or wavy parallel lines. Thousands upon thousands of tests were made, using these cards in a variety of ways. First, the subject to be tested for extra-sensory perception was given the cards sealed in an opaque envelope and he was invited to name the cards in the envelopes. Later other methods were used, among them one where the subject tried to name the top card of a deck lying on a table. The subjects included people in all walks of life and of all ages. The conditions and results were systematically recorded and evaluated.

The author explains that in a deck of 25 such cards the mean chance expectation is 5. In other words the chances of success in a test of this kind is 1 in 5 or the average would closely approximate this figure. Actual results of a great many tests exceeded this figure. They ran from 6.5 to 11 and higher. They seem to point in the direction of extra-sensory perception, particularly so when it was demonstrated that some subjects could, at will, lower their score to average or below, or raise it to their best. Results were just as remarkable in tests on telepathy, that is, where the subject or receiver attempts to apprehend the thoughts of a transmitting mind and at distances of a few feet to 250 miles.

After explaining the tests and the results, the author enters into a very interesting discussion as to the indications revealed, the conditions under which the tests were made, and the different types of subjects tested. He states, "There are fairly reliable indications that anyone in good health and free from worry, fatigue, or other limiting causes may do significant work (extra-sensory perception) if he can be interested and can be persuaded to coöperate fully and try patiently." Many of the results have been duplicated elsewhere than at Duke University.

Regardless of the reader's belief before reading the book, the story as here presented is interesting. The author does not try to sell the idea of the possibility of extra-sensory perception. He tells the story, gives the results, then his interpretation of them. It is his report of the work as it has so far progressed.

R. H. OPPERMANN.

A HANDBOOK FOR TESTING EXTRA-SENSORY PERCEPTION, arranged and edited by C. E. Stuart and J. G. Pratt, with a foreword by J. B. Rhine, accompanied by decks of cards and a record pad. 96 pages, 13 × 20 cms. New York, Farrar & Rinehart, Inc., 1937. Price $1.75.

Elsewhere in this JOURNAL there is reviewed a book entitled "New Frontiers of the Mind" by J. B. Rhine which describes experiments made at Duke University on the ability of the mind to perceive without the use of ordinary senses. The book at hand was written by men who have played important parts in the research at Duke. It describes simple tests, especially applicable by the layman, of extra-sensory perception with the use of cards similar to those used at the Duke University tests. The tests are of various kinds beginning with the more simple and advancing to the more complicated. Instructions are given on how to grade results and how to conduct the tests. Accompanying the handbook are three decks of cards and a record pad.

It is stated that this equipment is so made available to satisfy a demand on the part of the general public to test themselves and their friends for extra-sensory perception. The handbook certainly gives a clear explanation of how this can be done.

R. H. OPPERMANN.

LUBRICATING GREASES: THEIR MANUFACTURE AND USE, by E. N. Klemgard. 873 pages, tables, illustrations, 15 × 23 cms. New York Reinhold Publishing Corporation, 1937. Price $15.00.

This book is based on an earlier work published some ten years ago. Since then there has been an intense activity in the development of lubricating greases in order to meet the rising demand brought by the use of higher speeds, higher bearing pressures, new metallurgical compositions in bearings, and closer bearing clearances. These conditions apply equally to both the automotive and industrial branches of lubrication engineering. It is the lubrication engineer's task to keep pace with designers of machinery and it is the aim of this book to give assistance to facilitate this task. It is written from the standpoint of the producer as well as the user of lubricating greases and is devoted to greases exclusively.

The colloidal nature of lubricating greases is first discussed. It is pointed out that in general, greases consist of two phases, both exceedingly complex in nature, and both exhibiting definite colloidal properties not only when associated with each other, but when existing by themselves. Microscopic investigations of grease structure are reviewed and syneresis, "weeping," or "bleeding," of greases is discussed. The materials used in grease manufacture is the next major topic treated. These are discussed under divisions such as lubricating oils, asphaltic residue, petrolatum and waxes, soap stocks, fats, fillers, etc. Descriptions of all these important materials are quite complete, but what is unusual in a treatment of this kind is the listing of prices of many ingredients. The author explains that while the prices are rough figures, their reason is to show the relative costs.

The basic theory of lubricating grease manufacture is then taken up. The fundamental principles are made clear, those which underlie the processes for manufacturing calcium, sodium and aluminum base greases. This includes not only chemical information but data on mechanical agitation and its effect on rate of reaction and heat transfer, power consumption for agitating grease batches, and the cooling of batches. A portion of the book is devoted to the grease plant and its equipment. Here there are general descriptions of a few representative plants so as to gain some familiarity with typical installations. Individual pieces of equipment are then discussed.

The classification and formulae of many complex mixtures as well as many relatively simple compositions are then covered. These chapters classify grease with first consideration given to the predominating alkali or metal base, and secondarily the specific uses for which they are intended and the presence of special compounding materials. There is a vast amount of material here in a form readily usable. Inorganic hydrocarbon lubricants consisting of various solid lubricants dispersed in hydrocarbon lubricants, and organic lubricants and extreme pressure compounds are well covered. Under the heading of miscellaneous organic lubricants those greases and compositions are presented which depend on fats and brown oils, natural and synthetic waxes, resins, rubber, asphaltic residues, coal tar, ammonium compounds and carbohydrates, for their consistency or some special property. An appendix contains details for conducting the most ordinary chemical laboratory analyses and physical laboratory tests applicable to lubricating greases. A name and subject index completes the book.

The book contains a tremendous amount of material, gleaned from book,

periodical, and patent literature. There is also material presented which has not been discussed in prior literature. The method of presentation enables the book to be of great assistance to anyone whose interests lie in this direction.

R. H. OPPERMANN.

THE NATURE OF VARIABLE STARS, by Paul W. Merrill, 134 pages, plates, illustrations, 14 × 21 cms. New York, The Macmillan Co., 1938. Price $2.00.

The ever-increasing number of large telescopes, and their great achievements, has tended to overshadow completely the small instruments in the hands of amateur astronomers. But there is still a vast field for the little fellows. There is work which they can do quite efficiently and for which, therefore, it would be most uneconomical to employ the more powerful artillery. This is especially true of observations of variable stars, and the work of the American Association of Variable Star Observers, generally known as the AAVSO, consisting almost entirely of amateurs, is going far to solve the problems concerned with these numerous stars that vary more or less regularly in brilliance.

In producing a small elementary book devoted to these objects, Dr. Merrill, a distinguished member of the staff of the Mt. Wilson Observatory has filled a very definite need, and it may have the useful function of attracting new workers to this field. Thousands of amateur telescopes could be put to good use in this way.

But Dr. Merrill's book is not a handbook for the observer, amateur or professional. It is a clearly written account of present-day ideas. Few technical terms are used; when it is necessary to introduce them, they are fully explained. Many persons who have read one or more of the numerous excellent books on popular astronomy published in the last few years will find it of interest as dealing with one important phase of astronomy in a more detailed manner. And even to one who has not had this introduction, it will, as the author states in the Preface, "help him to understand the sort of thing with which astronomers are occupied, and why their work has so many points of contact with other sciences."

Of particular interest to many readers will be his chapter on the "novae," or "new" stars, those bodies which suddenly "swell up and burst," in the words of a famous telegram which is quoted.

"The outflow of light and heat from a star," says Dr. Merrill, "may be compared with a stream of water from a reservoir. The behavior of an ordinary star corresponds to the steady flow of water through a pipe of a certain size; of a periodic variable to a pulsating flow caused by a regular rise and fall of the level of water in the reservoir or to some automatic geyser-like action of the outlet system; in a nova, the dam breaks."

Just what makes it break is yet to be determined. At present, he admits, we know much more about how a star varies than why. But gradually knowledge is coming, and this knowledge will tell us far more about stellar evolution in general. Therein lies the great importance of the study of variable stars.

To one like Dr. Merrill, who is working in this very field, the gaps in our knowledge are strikingly apparent, and throughout there is a refreshing lack of dogmatism. "The story of our knowledge of stellar evolution is a sad one of small successes and large blunders," he says. His warning against placing too much faith in theoretical conclusions is also worth quoting:

"We can see but a very small fraction of the radius into any star, even a highly tenuous long-period variable. Thus the only portions accessible to direct observation are the extreme outer layers. The only way to learn about the interior is by what Eddington has called an 'analytical boring machine, which is supposed to bore mathematically into the interior and to bring up a sample. The trouble is that the drill takes down some of the engineer's ideas and hypotheses and these so color the material brought up that we are a bit uncertain as to its original properties.' Technical journals are filled with elaborate papers on conditions in the interiors of model gaseous spheres, but these discussions have, for the most part, the character of exercises in mathematical physics rather than astronomical investigations, and it is difficult to judge the degree of resemblance between the models and actual stars. Differential equations are like servants in livery: it is honorable to be able to command them, but they are 'yes' men, loyally giving support and amplification to the ideas entrusted to them by their master."

The plates and the diagrams are well selected, and aid in the explanations. Mechanically, the book is all that could be desired, and two indices, one of stars, the other of subjects, materially add to its usefulness.

JAMES STOKLEY.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, TRANSACTIONS, Vol. 125, Iron and Steel Division. 602 pages, plates, illustrations, tables, 15 × 23 cms. New York, Institute, 1937. Price $5.00.

This is the tenth of a series containing papers before the Iron and Steel division of this society. It covers the meetings of October 1936 and February 1937, and contains such interesting papers as Dr. P. D. Merica's Memorial Lecture on Progress in Improvement of Cast Iron and Use of Alloys in Iron, a paper on Blast Furnace Practice by J. M. Hassler, and the Freezing of Cast Iron by Alfred Boyles. There is a comprehensive index in the back of the volume which adds materially to its value.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Hydro- and Aero-Dynamics, by S. L. Green. 185 pages, illustrations, 14 × 22 cms. New York, Pitman Publishing Corporation, 1937. Price $3.50.

The Chemistry of Petroleum Derivatives, by Carleton Ellis. Volume II, 1937. 1464 pages, illustrations, 16 × 23 cms. New York, Reinhold Publishing Corporation. Price $20.00.

Segmental Functions, Text and Tables, by C. K. Smoley. 435 pages, 12 × 18 cms. Scranton, C. K. Smoley and Sons, 1937. Price $5.00.

Etude Pratique des Rayonnements, Solaire, Atmosphérique et Terrestre (Méthodes et Résultats), par Ch. Maurain. 180 pages, illustrations, tables, 16 × 25 cms. Paris, Gauthier-Villars, 1937. Price 80 fr.

The Fine Structure of Matter, The Bearing of Recent Work on Crystal Structure, Polarization and Line Spectra, being Volume II of a comprehensive treatise of atomic and molecular structure. Part I: X-Rays and the Structure of Matter, by

C. H. Douglas Clark. 216 pages, illustrations, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1937. Price $4.25.

Earth-Lore, Geology without Jargon, by Professor S. J. Shand. 144 pages, plates, illustrations, 14 × 20 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $1.25.

Consumer Goods, How to Know and Use Them, by Edward Reich and Carlton John Siegler. 526 pages, illustrations, 15 × 22 cms. New York, American Book Company, 1937.

National Advisory Committee for Aeronautics, Twenty-Third Annual Report, 1937. 47 pages, plates. Price 15 cents. Report No. 608, Stress Analysis of Beams with Shear Deformation of the Flanges, by Paul Kuhn. 19 pages, illustrations. Price 10 cents. Technical Notes: No. 625, Spinning Characteristics of Wings, IV—Changes in Stagger of Rectangular Clark Y Biplane Cellules, by M. J. Bamber and R. O. House. 29 pages, illustrations. No. 626, Static Thrust Analysis of the Lifting Airscrews, by Montgomery Knight and Ralph A. Hefner. 61 pages, illustrations, tables. No. 627, Pressure Distribution over a Clark Y–H Airfoil Section with a Split Flap, by Carl J. Wenzinger. 12 pages, illustrations. No. 628, Plastics as Structural Material for Aircraft, by G. M. Kline. 26 pages, illustrations. No. 630, Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails, II. Mass Distributed Along the Fuselage, by Oscar Seidman and A. I. Neihouse. 28 pages, illustrations. 8 pamphlets, 20 × 26 cms. Washington, Committee, 1937.

U. S. Department of Commerce, National Bureau of Standards. Code for Protection against Lightning, Parts I, II, and III. National Bureau of Standards Handbook H21. 96 pages, 13 × 19 cms. Price 15 cents. Magnetic Testing, by Raymond L. Sanford, Circular of the National Bureau of Standards C415. 34 pages, illustrations, 15 × 23 cms. Price 10 cents. Washington, Superintendent of Documents, 1937.

Bell Telephone System, Monographs: B-1006, A Model of Ferromagnetic Action, by R. M. Bozorth and J. F. Dillinger. 10 pages, illustrations. B-1008 Moisture Adsorption in Cotton and other Fibrous Insulating Materials, by Albert C. Walker. 20 pages, illustrations. B-1009, A High-Precision Sound-Film Recording Machine, by H. Pfannenstiehl. 7 pages, illustrations. 3 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1937.

CURRENT TOPICS.

Unusual Train Wreck Fails to Dislodge Steel Truss.—(*Engineering News Record*, Vol. 119, No. 15.) A bridge with a span of 150 feet at Bridgeville, Pa., was the scene recently of a freak railway accident. Due to a burned journal on the eighth car of a fast east bound freight train there was a derailment of nineteen following cars. Ten of the derailed cars piled up within the truss span, and one refrigerator car passed through the side of the north truss and dropped to the bed of Chartiers Creek below. The train is said to have been traveling at a speed of from 35 to 40 miles per hour. Despite the terrific punishment inflicted on the double track span, it did not collapse and is now being repaired by replacing the damaged members. The bridge was built in 1902 and was designed for Coopers E-40 loading. In 1936–7 the truss was reinforced to carry the equivalent of Coopers E-65 loading.

R. H. O.

Air Electrically Cleaned in Chicago Building.—(*Electrical World*, Vol. 108, No. 17.) First major installation of an electrostatic air cleaner for office building air conditioning has been made in the Field Building, tallest in Chicago's Loop, by the Westinghouse Electric & Manufacturing Company. The installation is in five sections in different fan rooms, one in the basement and one each on the first four floors. The eighteen units comprised in the five sections are capable of cleaning 272,000 cubic feet of air each minute. In a year's time it is estimated, the installations will have collected approximately 600 bushels of impurities, 90 per cent. of which will consist of particles one-hundredth the diameter of human hair. By weight, the collection will consist of one third ash, another third fixed carbon, soot, lampblack and other derivatives, and the remaining third volatile matter such as oils and greases. Sulphur, bacteria, pollen in season, and other substances found in suspension in the atmosphere in any city, are also deposited on the plates. All of which is not remarkable when it is considered that dirt deposited out of the area in the Loop area averages a thousand tons per year per square mile. Dust particles so small that they flow through any mechanical filter are removed by this process of electrical precipitation. Impurities are taken from the air, not by sifting them out mechanically, but by charging all particles electrically and then pull-

ing them out as they pass through an electrostatic field. The energy required to do this work is remarkably small.

R. H. O.

A Condensing Top.—N. D. GOVE, design engineer for the Westinghouse Electric & Manufacturing Co.'s South Philadelphia works states in *Power*, Vol. 81, No. 12, that while superposition, the topping of steam plants by new high pressure non-condensing units, has been playing a leading part in the present advance of the central station, another principle manifested in the superposition condensing turbine has been developed and is being rapidly put into practice by the building of the first unit of this type in the Westinghouse shops. The unit is rated at 30,000 kw. It is a natural evolution of the bleeder turbine supplying steam for process heating. In this new application, however, steam extracted passes to the throttle of a low pressure unit and continues its expansion just as if it had come originally from the low pressure boiler system. The high pressure unit is partly a superposition turbine, while the succeeding stages are typically those of a condensing machine. When steam is not bled for the older unit, the high pressure unit operates on the normal condensing or regenerative cycle. Extensive adoption of the superposition condensing principle is expected, since it combines the advantages of superposition with the requirement of new condensing capacity. Whether the new unit is considered as developing a block of low cost by-product power or whether the combined units are considered as working together on a modern steam cycle is immaterial, because the gains evaluated either way are great enough to make it attractive.

R. H. O.

Liquefied Air Used to Run Boat Engine.—HERBERT LEOPOLD of Tokyo, Japan, describes a remarkable engine producing power from liquefied air in an enclosed cycle and operating at a temperature of $-139°$ C., in *Refrigerating Engineering*, Vol. 34, No. 5. The engine was installed in a 27 ft. long boat which developed a speed of 4.6 miles an hour cruising off Shibaura, Tokyo, for one and one half hours. Revolutionary when compared with the conventional idea of engines, the invention consumes no petroleum fuel, electricity or other high temperature medium, but operates by the energy obtainable from the evaporation of liquefied air. Moreover the engine does not exhaust the air thus vaporized but liquefies it again and utilizes it for the same purpose over and over again; hence the engine operates continuously by the addition of only a small quantity of air in order to make up for leakage from valves and other con-

necting parts in the system. The engine, invented by Yoshinosuke Shibukawa, founder and chief engineer of the Shimizu Low Temperature Research Laboratory, consists of a container of liquefied air, a pump, a vaporizer, a prime mover, and a liquefier. The liquefied air in the container is led into a vaporizer through the pump. The pump is made of a copper alloy, developed by the laboratory for that special purpose, which is capable of withstanding the low temperature without freezing or cracking. It is considered that this invention was one of the two most outstanding engineering attainments in Japan during the year. The engine will be enlarged to a several hundred horsepower machine in the next year or two, now that it has demonstrated its practical possibility. Its applications to big power plants will call for many more technical problems to be solved.

R. H. O.

Air Conditioning For Industrial Workers.—C. L. HUBBARD. (*Power Plant Engineering*, Vol. XLI, No. 11.) It is a well known fact that the physical comfort of workers in industrial establishments has an important bearing upon both quantity and quality of the output. The effect varies considerably in different cases. In the case of hand work and hand controlled machines it is more pronounced than where extensive use is made of automatic or semi-automatic machinery although under both conditions slowing down of the work, industrial unrest, and loss of time through sickness often results from physical discomfort. It seems to be a proven fact that the longer a person works continuously, the less he accomplishes in a given time. Physical comfort depends largely upon the body temperature, and this in turn upon the relation between the rate of heat production and dissipation. In other words, to maintain a uniform temperature, which is essential to both comfort and health it is necessary to remove heat from the body at the same rate that it is produced. It has been found that within certain limits, various combinations of temperature, humidity, and air motion will give satisfactory results. As a guide for securing these results with standard ventilating equipment, tables are published by the American Society of Heating and Ventilating Engineers. Air conditioning equipment can be adjusted in accordance with these tables, covering a considerable range with respect to outside weather conditions.

R. H. O.

A New Low-Alloy Steel for High-Temperature Service.—C. L. CLARK AND R. S. BROWN describe, in *Combustion*, Vol. 9, No. 4, the high temperature characteristics of a 1.5 per cent. molybdenum

steel in the calorized condition. The molybdenum in this amount provides the strength characteristics while the calorized surface produces a high degree of oxidation and sulphur-corrosion resistance, which are properties advantageous to higher operating temperatures. In the uncalorized state this analysis would possess an oxidation resistance no better than that of a plain carbon steel and in this condition its use would be confined to a maximum operating temperature of 950° F. to 1000° F. When the surfaces are calorized, however, this analysis can be used under properly designed stresses for prolonged service at temperatures up to 1200° to 1300° F. In general the use of this material has thus far been for tubes, rods and bolts. There are two partial installations of radiant superheaters and for one of these a most satisfactory operating report has been given. There is one installation of liquid phase cracking of very heavy cracked residuum oil heated to 1030° F. with the unusually high rate of heat input of 18,000 B.t.u. per sq. ft. of surface per hour, which makes for high tube wall temperatures. Another installation is used to heat petroleum vapor under pressure to 1400° F. The calorized molybdenum tube may be rolled into headers without damage to the calorized surface inside.

R. H. O.

Electron Diffraction, a New Tool for Research.—C. S. BARRETT. (*Metal Progress*, Vol. 32, No. 5.) It was not many years ago that diffraction of electrons by crystals was considered a somewhat useless phenomenon, but rapid developments are changing this so that electron diffraction is now placed as a tool for research. When a stream of electrons encounters a crystal it behaves in all respects like a train of waves: It is diffracted like a beam of light is diffracted by a grating of evenly spaced lines, or like X-rays are diffracted by the regularly spaced atoms of a crystalline substance. By means of an electron diffraction camera it is possible to direct an electron beam at a specimen and photograph the diffracted or "reflected" beams which are caused by interaction with the atoms of the specimen. The pattern that appears on the film after it is developed is similar to the diffraction patterns produced by X-rays, the principal difference being that it is confined to a much narrower range of angles because of the shorter wave-length of the electrons. One striking characteristic of this method is that it takes only a fraction of a second exposure time for the photographic film compared to the hours required in X-ray work. One of the most successful applications of the method is the study of thin metallic films including those produced by electro-deposition, sputtering, precipitation from colloidal suspension, oxidation, condensation of metal vapors, etc.

In this field electron diffraction is able to provide the same kind of information that X-ray diffraction provides for thicker layers; namely, the identification of the phases in the layer and their crystal structures, the approximate grain size in the layer, the state of strain in the layer, and the orientation of the grains.

R. H. O.

Now, a Perpetual Flame Fed Only by Water.—NEIL HITT. (*Refrigerating Engineering*, Vol. 34, No. 6.) For decades conservationists have been wringing their hands over what is to be substituted when we have pilfered and squandered the last of the earth's resources. With regard to fuel, the device of Otto H. Mohr of Concord, California, may give them cause to rest a little easier. Mr. Mohr utilizes the sun's rays. First he pours a gallon of water onto an absorbent material inside a shallow box, well insulated, about 2 feet square, and covered with glass. Within a few hours, depending upon how brightly the sun shines, the water gradually becomes a vapor. In the meantime the sun's rays are also concentrated on thermocouples enclosed in a vacuum bulb. The lower ends of the couples are cooled by exposure to air and the difference in temperature will produce sufficient electricity for passing through the water vapor. This is done by passing the water vapor through a small chamber containing an activating or conditioning agent. Two electrodes are so situated that the electric current passes through the water vapor, separating the oxygen and hydrogen in the water. Oxygen is at present discarded. Hydrogen is stored and used for burning when needed. It is estimated that a plant to consume 3 gallons of water per day would be large enough to provide the ordinary household with sufficient gas for all domestic needs including cooking, water heating, lighting, air conditioning and the operation of a refrigerator. This plant, the commercial manufacture of which will not begin for at least a year, Mr. Mohr states, would last a lifetime, the initial cost would be small, and would entail no further expense. When properly insulated and installed, changes in atmospheric temperature will have little or no effect upon it.

R. H. O.

Office Building Without Precedent.—(*Engineering News Record*, Vol. 119, No. 24.) A creation of FRANK LLOYD WRIGHT, internationally known architect, the home office of S. C. Johnson & Son, Inc., wax makers of Racine, Wis., is a leap into the future with regard to style of architecture, structural details, arrangement of materials, and in construction procedure. The main building is one

large workroom 130 × 210 ft. in plan and 20 ft. high. Girdling this on three sides is a mezzanine gallery 18 ft. wide and clearing the first floor by only 7 ft. on which are located offices of department heads. The fourth side faces a lobby 30 ft. high. Executive offices are grouped around the upper portion of the lobby. Of structural interest are a new form of "morning glory" column—slim, tapering hollow concrete shafts topped by shallow flaring caps; a multi-domed flat roof slab; monolithic walls of brick faces on both sides, concrete and cork interior; and exceptional use of expanded metal for reinforcing. There is no general basement under the building, but a service tunnel runs across the lot, and two long underground corridors serve as rest rooms and lavatories. The heating system is an innovation, for the main building floor will act as a radiator with steam pipes placed under the floor slab. The executive offices and other smaller rooms will be heated through an air conditioning system. True air conditioning will prevail throughout the year. A refrigerating system will cool the air in hot weather. The building also contains a covered driveway and a covered parking space designated a "carport." Next to this is a garage and service station. The center part of this structure rises two stories to include a fully enclosed squash court, connected to the executive offices by a covered bridge. The roof of the carport will be a recreation deck.

R. H. O.

American Standards Association.—Rounding out its 19th year of service as national standardizing agency, the American Standards Association reported the largest increase in membership of any year since the Association was formed. The growth in membership, DANA D. BARNUM, the Association's president, stated, shows an increased interest on the part of industry in standardization. Fifty-nine standards were approved during the past year. There are two new projects in the field of consumer goods. In answer to the question as to whether the same practical engineering methods that have for many years proved effective in the development of mechanical standards and codes be applied to this field, Mr. Barnum reported that five of the chief national consumer organizations and many retail executives believe they can. In this belief they are utilizing the American Standards Association to develop a program of standards in the consumer field that may become one of the Association's major operations.

R. H. O.